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AN AUTOMATIC RECORDING POTENTIOMETER FOR INDUSTRIAL USE

by H. J. ROOSDORP.

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In electrical equipment for the measurement and control of industrial processes, high sensitivity and accuracy must be combined with robust construction and reliability. The following article describes an instrument operating on the null principle and automatically balanced, which goes a long way towards meeting these requirements.

The great progress in electronics, which has made such a valuable contribution to the development of telecommunications, has also resulted in great improvements in the field of electrical measurement. Much thought has also been devoted to the problem of applying these perfected measuring techniques to the measurement of non-electrical quantities. In order that such measurements may be effected with the aid of electrical equipment, it is necessary to convert the quantity to be measured to a corresponding electrical quantity. Devices that will do this are known in general as transducers, and examples of these are given in the table.

From this table it will be seen that most of the electrical quantities produced by such transducers are D.C. voltage or resistance values. This is not altogether fortuitous, for these quantities can be easily and accurately measured: the transducer employed for any particular purpose is chosen to give the most suitable electrical quantity for measurement.

In this article an instrument will be described which is capable of measuring very accurately direct voltages, resistances or even impedances, and which, because of its robust construction, is suitable (in conjunction with some form of transducer) for the measurement, recording or automatic control of many non-electrical quantities in industry [1].

Quantity to be measured	Transducer	Electrical quantity
Temperature	Thermocouple	D.C. voltage
	Resistance thermometer	Resistance
	Total radiation pyrometer	D.C. voltage or resistance
Pressure Force (weight)	Strain gauge	Resistance
Displacement	Differential transformer	Self inductance
Rate of flow of gas or liquid	Diaphragm with pressure difference pick up	Resistance or self inductance
Humidity	Dew-point pickup (resistance thermometer)	Resistance
	Wet and dry bulb, with resistance thermometer	Resistance
	Conductivity pickup	Resistance
pH	Glass-calomel electrode	D.C. voltage
Luminous intensity	Photo-electric cell	D.C. voltage
	Barrier-layer cell	Resistance
Ionizing radiations	Ionization chamber	Direct current
	Geiger counter	Direct current

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[1] A recording instrument somewhat similar to that described here was designed in the Philips Laboratories during the war.

Measuring methods

Voltages, currents and impedances can be measured in accordance with two different principles, viz. the deflection method and the null or comparison method. Some instruments using the first method are, e.g., electrostatic voltmeters for voltages, moving-coil and moving-iron instruments for currents, and the cross-field or cross-coil type of instrument for impedances.

The great advantage of the deflection system is that it gives a *direct* reading, which bears a known relationship to the quantity to be measured. It suffers from the drawback, however, that the measuring instrument itself determines the attainable accuracy, which may not always be adequate. Another disadvantage is that a certain amount of power is required to produce the needle deflection, so that, if the transducer is capable of delivering only a very small amount of power, an extremely sensitive instrument, or alternatively an amplifier, has to be used. In the latter instance, the measuring accuracy is also dependent on the stability of the amplification.

With the null method, the unknown quantity is compared with another (known) quantity of the same kind. This can be done by means of a bridge circuit or a potentiometer. Only a detecting instrument is then required and the accuracy of the measurement does not then depend on that of the instrument but only on the comparison elements (e.g. standard resistances). Also, since the instrument is employed only as a zero indicator, it can be made very much more sensitive than those of the direct-reading type. (Moreover, the sensitivity can in this case be increased by using an amplifier, the amplification of which need not be known, or constant).

The null method thus provides at once greater sensitivity and accuracy than the direct-reading system. The only disadvantage of the null method is that an adjustment has always to be made before the value of the unknown quantity can be obtained from the known comparison quantity.

Automatic balance

The comparison or null method is normally employed when precise measurements are required. The disadvantage of having to adjust the balance manually for each and every measurement can be eliminated by using a servo motor to effect the adjustment automatically ²). With such an "automatic bridge" the quantity to be measured is thus read direct, so that here we have in effect a direct-reading instrument. Another great advantage of the servo motor is that it makes a much larger force available than the conventional direct-reading system. The null method with automatic balance therefore provides better facilities for connecting the measuring system to a recording mechanism to provide a continuous record.

The following numerical example will serve to illustrate this.

In a moving-coil meter the driving torque is:

$$M = B\, i\, l\, d\, w, \quad . \; . \; . \; . \; . \; . \quad (1)$$

where:

M = torque in N·m *),

B = magnetic induction in the air-gap, in Wb/m² (1 Wb/m² = 10⁴ gauss),

i = current in Amps flowing in the coil,

l = length in m, of that part of the coil within the magnetic field,

d = diameter of coil in m,

w = number of turns.

If the resistance of the coil is, say, 400 Ω, the current i, for the measurement of a voltage of 10 mV (e.g. from a thermocouple), is 25 μA. Now, if we further assume that $B = 0.3$ Wb/m², $l = 3$ cm, $d = 2$ cm and $w = 1000$, the torque will be 4.5×10^{-4} N.cm = 46 mg.cm. This torque must counterbalance that of the spiral springs. When the current to be measured is varied, the difference between the torque applied to the moving coil by the magnetic field and that of the spiral springs is available for the variation in the deflection of the needle.

If the current varies, say 1%, a torque of 0.46 mg.cm is available for the deflection. The force applied to the end of a needle 10 cm in length is then 46 μg, which is just enough to initiate an indication, but quite inadequate for direct recording purposes.

The amount of force delivered can be increased by means of an amplifier, but the amplification that can be employed is limited by the maximum dissipation of the moving coil. Assuming this to be 1 W, and again taking the resistance of the coil to be 400 Ω, the maximum current that the coil will carry is 50 mA. The maximum possible torque is then 2000 times greater than in the example given above; a force equal to 92 mg will now be available at the extremity of a needle 10 cm long. This is just sufficient to drive an inking stylus, but the greatest care would have to be taken in the design and operation of such an instrument.

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²) An early example of a measuring circuit embodying this principle was described in this Review by R. Vermeulen, Philips tech. Rev. 4, 354-363, 1939.

*) N = Newton, the unit of force in the M.K.S. system (= 10⁵ dynes).

Using the null method with a servo-driven balancing mechanism as described below, a force of some hundreds of grammes is available. This force is supplied by an induction motor, to the control winding of which a power of about 4 W is applied by an amplifier. (To obtain so much force at the pointer of a moving-coil direct-reading instrument, 10^{10} W would have to be applied to give full-scale deflection!)

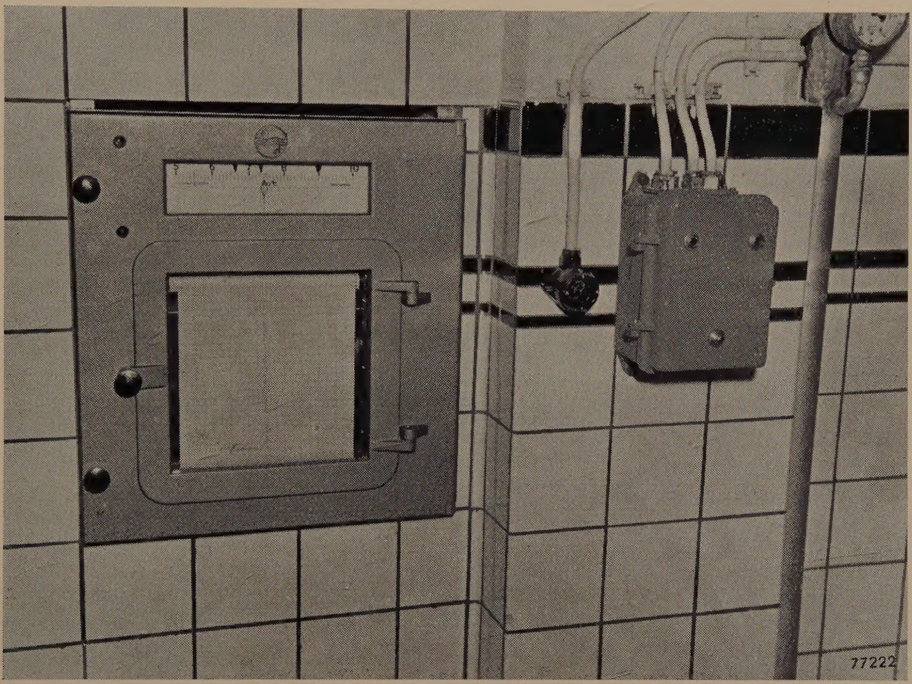

Fig. 1. The automatic measuring and recording bridge (type PR 2000) used for measuring and recording the temperature for the pasteurisation of milk.

A measuring circuit operated on the null principle and incorporating automatic balancing can be quite easily designed for a setting time very much shorter than that of a sensitive direct-reading instrument without an amplifier. Equipment can be made for industrial purposes in which the time necessary for traversing the whole scale is less than 1 sec.

For industrial applications, the null method with automatic balancing accordingly has many advantages, viz. high accuracy, considerable power and high speed. The equipment about to be described based on this system, will measure voltages and impedances and, if necessary, record them [3]).

Fig. 1 shows the unit employed for measuring and recording the temperature for the pasteurization of milk.

Principle of the automatic bridge

Figures 2, 3, 4 and 5 depict a number of circuits suitable for the measurement of direct voltages, and resistances, by the null method with automatic balance.

In *fig. 2* the voltage E_x from a thermocouple is compared with a voltage E_0 from a potentiometer connected to a source E_n whose voltage is precisely known. The difference E_i (the so-called error voltage) between E_x and E_0 is applied to an amplifier A, and the amplified voltage is used to drive a motor M which is coupled mechanically to the contact of the slidewire R_n. This contact is always moved by the motor in the direction that will reduce the difference between E_x and E_0. Provided that the amplification by A is sufficient, the motor operates

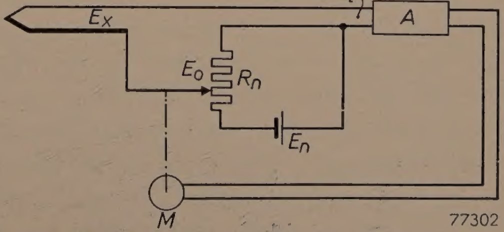

Fig. 2. Basic potentiometer circuit for measuring the voltage E_x of a thermocouple by the null method with automatic balance. E_n source of reference voltage. R_n potentiometer slidewire. A amplifier. M motor. The motor sets the contact of the slidewire to the point where the difference E_i between E_x and E_0 is practically zero.

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[3]) Series PR 1000 for indicating, and series PR 2000 for recording instruments. The use of the automatic potentiometer/bridge for the control of industrial processes will be dealt with in a subsequent article.

at very low values of E_i, so that, practically speaking, when the motor stops, E_0 is equal to E_x. Accordingly, E_x can be read from a scale mounted on R_n.

In many cases it may be desirable to have the adjustment corresponding to zero voltage at a point other than the beginning of the scale; e.g. in measurements over a range of say from 50 to 150 V instead of 0—100 V, or where the range of measurement covers both positive and negative voltages (e.g. from —10 to + 100 mV). To achieve this, the potentiometer is made into a bridge circuit (*fig. 3*), which has the additional advantage that variable resistors (e.g. temperature-dependent resistors) can be included in one or more of the bridge arms, in order to render the circuit independent of certain disturbing effects. In this way, for example, compensation can be provided for variation in the e.m.f. of a thermocouple due to changes in temperature at the cold junction.

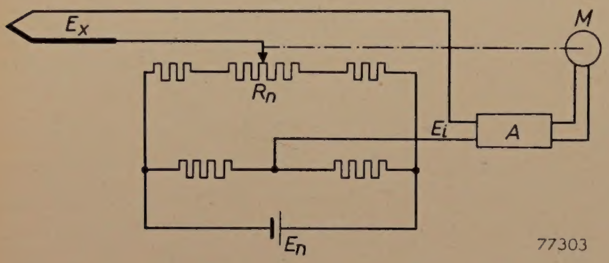

Fig. 3. Potentiometer circuit for measuring the voltage E_x of a thermocouple. With this arrangement, zero voltage may be made to correspond to any point along the length of the slidewire. The balancing voltage is obtained from a bridge circuit.

Fig. 4 shows a circuit suitable for the measurement of the resistance R_x of a resistance-thermometer. In the simplest form of circuit, this resistance is included in one of the arms of the bridge. Here again the sliding contact of the potentiometer R_n is moved by the motor M in such a way as to balance the bridge so that the error voltage E_i delivered to the amplifier A will be practically zero.

In *fig. 5* we illustrate a circuit that is widely employed in conjunction with strain gauges. These gauges, represented in the figure by the resistances R_s, are wired up in the form of a bridge, so as to balance out the effect of any resistance variations in the connections. Measurement is effected with the aid of a second bridge circuit in which the measuring slidewire, controlled by the motor M is included. Both bridges are fed from a single transformer; the motor sets the slider of R_n to the point where the voltage between points *a* and *b* is the same as that between *c* and *d*: at this point the adjustment is complete and the motor stops since the error voltage E_i applied to the amplifier is then effectively zero.

With sufficient amplification, the accuracy of measurement is determined by the tolerance within which the resistance values or the potential E_n can be set. For industrial use this type of instrument is usually calibrated to an accuracy within $\frac{1}{4}\%$.

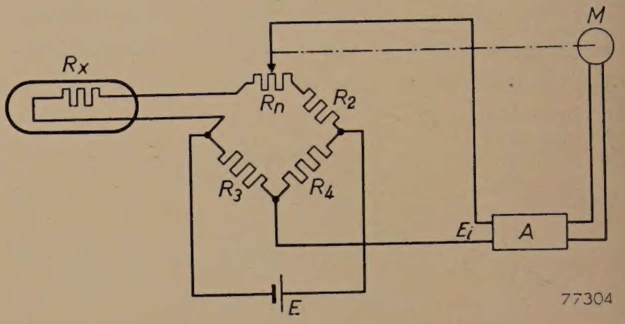

Fig. 4. Simple bridge circuit for measuring the resistance R_x of a resistance thermometer.

The sensitivity, that is the lowest value of E_i at which the motor will revolve, is determined by the amplification from A. Very high amplification can be combined with robust construction in electronic equipment, to give an effective sensitivity of 1 μV.

The speed at which the adjustment is effected is governed by the design of the servo system. With a high-speed motor the time can be made very short, viz. less than 1 sec, but there is then some risk of the balancing mechanism maintaining an oscillation about the point of balance. To prevent this, the mechanism must be damped. The amount of damping required can be computed in the following manner.

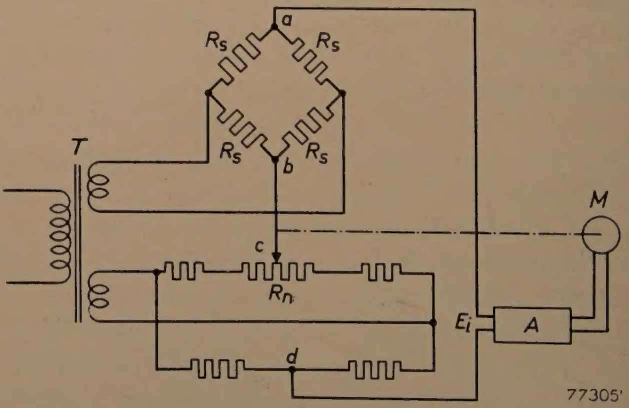

Fig. 5. Circuit for strain gauge measurements. The gauges, represented by the resistances R_s, are connected as a bridge circuit. The slidewire R_n is included in a second bridge circuit, and the two bridges are fed from a single transformer T. The motor sets the slider on R_n to the point where the difference E_i between the voltage across *a-b* and the voltage across *c-d* is practically zero.

In *fig. 6* the point on the slidewire R_n corresponding to zero voltage applied to the amplifier A, is denoted by O. Let us employ the following notation:

x = displacement of the slider from the point O;
vx = voltage applied to the amplifier A, corresponding to displacement x;
a = amplification provided by A;
$kavx$ = force applied by the motor M to the moving parts when a voltage avx is applied to it;
m = mass of the moving parts.

With no damping applied to the slider, the equation of motion is

$$m\frac{d^2x}{dt^2}+kavx=0. \quad . \quad . \quad . \quad . \quad (2)$$

The values of x satisfying this equation may be represented as a function of time by an undamped oscillation of angular frequency given by

$$\omega=\sqrt{\frac{kav}{m}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

We shall now suppose that a damping force is present which is proportional to the velocity of the moving parts. For a velocity dx/dt, let this damping force be $p dx/dt$; the equation of motion is then:

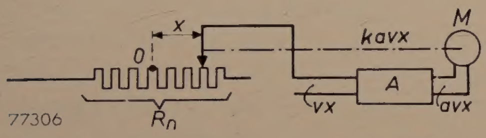

Fig. 6. When the contact of the slidewire R_n is located at a distance x from the point of balance O, a voltage vx is applied to the amplifier A. The amplifier then delivers a voltage avx which causes the motor to exert a force $kavx$ on the slider.

$$m\frac{d^2x}{dt^2}+p\frac{dx}{dt}+kavx=0. \quad . \quad . \quad . \quad (4)$$

From this it follows that x as a function of time can be represented by a damped oscillation whose amplitude is proportional to $e^{-pt/2m}$. As with most measuring instruments, what we require is aperiodic motion, so that the value of p will have to be high enough to introduce critical damping. This occurs when:

$$p^2=4\,mkav. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Mechanically, it is extremely difficult to obtain a reproducible value of p. Electrically, however, this is quite a simple matter; in effect, the motor M is coupled to a tachometer generator G, which delivers a voltage that is proportional to the speed. For a speed of dx/dt, let this voltage be represented by $g dx/dt$. This voltage from the generator G, together with that from the potentiometer R_n, is supplied to the input of the amplifier (*fig. 7*). Without the mechanical damping, the equation of motion is now

$$m\frac{d^2x}{dt^2}+ka\left(vx+g\frac{dx}{dt}\right)=0. \quad . \quad . \quad (6)$$

The solution of this equation, giving x as a function of time, may be represented by a damped oscillation of amplitude proportional to $e^{-kagt/2m}$.

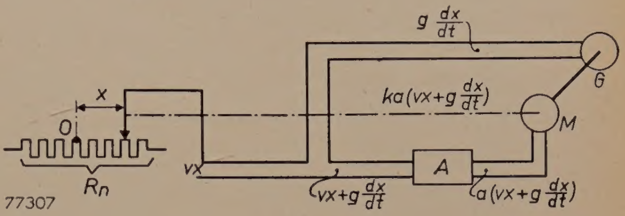

Fig. 7. A tachometer-generator G, coupled directly to the motor M, delivers a voltage that is proportional to the speed. This voltage is added to the input of the amplifier, producing an electrical damping of the balancing mechanism.

Critical damping occurs when

$$g^2=\frac{4\,mv}{ka}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The damping can accordingly be adjusted to the required value by varying the output from the generator (i.e. by varying g).

To ensure high sensitivity, it is essential that the motor, even for the smallest value $x_{\min}$ of the displacement x, delivers a certain minimum power $K_{\min}$ to drive the recording mechanism, viz.

$$kavx_{\min}=K_{\min}, \quad . \quad . \quad . \quad . \quad . \quad (8)$$

and the required amplification is, therefore,

$$a=\frac{K_{\min}}{kv\,x_{\min}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

From (7) and (9) it follows that the value of g at which critical damping occurs is given by

$$g^2=\frac{4\,m\,v^2x_{\min}}{K_{\min}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

We see from (9) and (10) that the desired values of a and g are dependent on v, that is, on the measuring range. If measurements are to be made in any other range, both g and a have to be re-adjusted, but this can be obviated by splitting the amplifier into two parts, A_1 and A_2, in the manner shown in *fig. 8*. The equation of motion is now obtained by replacing v in (6) by va_1, and a by a_2. According to (8) the following equation must be satisfied if the recording mechanism is to operate at a small value $x_{\min}$ of the displacement x:

$$k\,a_1\,a_2\,v\,x_{\min} = K_{\min}\,,$$

or

$$a_1 = \frac{K_{\min}}{k\,a_2\,v\,x_{\min}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

Critical damping occurs when

$$g^2 = \frac{4\,m\,v\,a_1}{k\,a_2}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

from which, together with (11),

$$g^2 = \frac{4\,m\,K_{\min}}{k^2\,a_2^2\,x_{\min}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

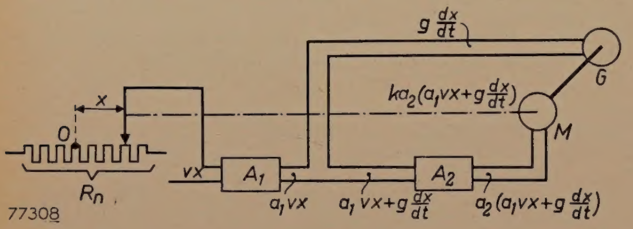

Fig. 8. With the amplifier divided in two sections, A_1 and A_2, it is not necessary, when the measuring range is changed, to modify both the voltage which the generator delivers at a given speed (factor g) and, at the same time, the amplification. It is sufficient to vary only the amplification a_1 of the amplifier section A_1.

This shows that g is now independent of v. When the measuring range is varied, g need not be re-adjusted; in accordance with (11) it is sufficient to adjust a_1.

Construction

The general arrangement of the automatic bridge is shown in the diagram in *fig. 9*. The resistors, which together with the slidewire R_n, form the bridge circuit proper, are grouped in the form of an interchangeable unit B corresponding to the required measuring range. The latter can then be changed simply by replacing the unit B. The slider of R_n is mounted on a cursor W which is moved along the rail C by the motor M through gearing and a friction drive D. A pointer indicates the position of the cursor on a scale S. The rotor of the tachometer generator G is coupled to the shaft of the motor M. The amplifiers and supply units, in the form of interchangeable units, are mounted in a rack E. Unit *1* supplies a voltage E_B to feed the measuring element. Unit *2* is the amplifier denoted by A_1 in fig. 8. The amplifier shown in that figure as A_2 is in two sections, *3* and *4*, of which *3* receives both the output voltage from *2* and the voltage E_G from the generator. Unit *4* is the output stage, of which the output voltage E_u is applied to the motor M. Lastly, the supply voltages for the two amplifiers are furnished by unit *5*.

Between *4* and *5*, other units can be placed in circuit when the equipment is to be used for automatic control, but these will not be discussed here [3]).

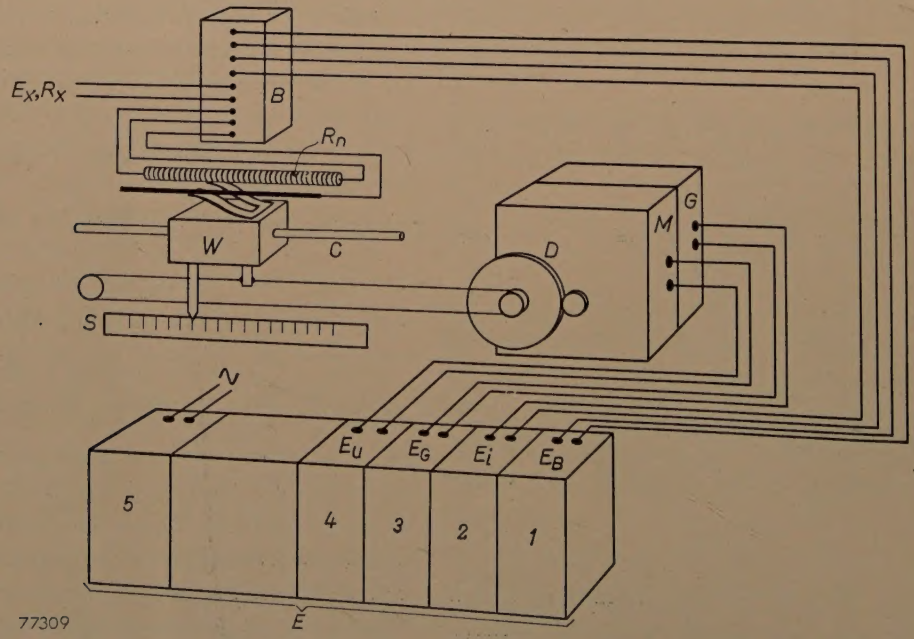

Fig. 9. Block diagram of automatic potentiometer bridge, types PR 1000 and PR 2000. The cursor W, which is moved along the rail C by the motor M through a friction drive, carries both the slidewire contact and the pointer, which moves along the scale S.

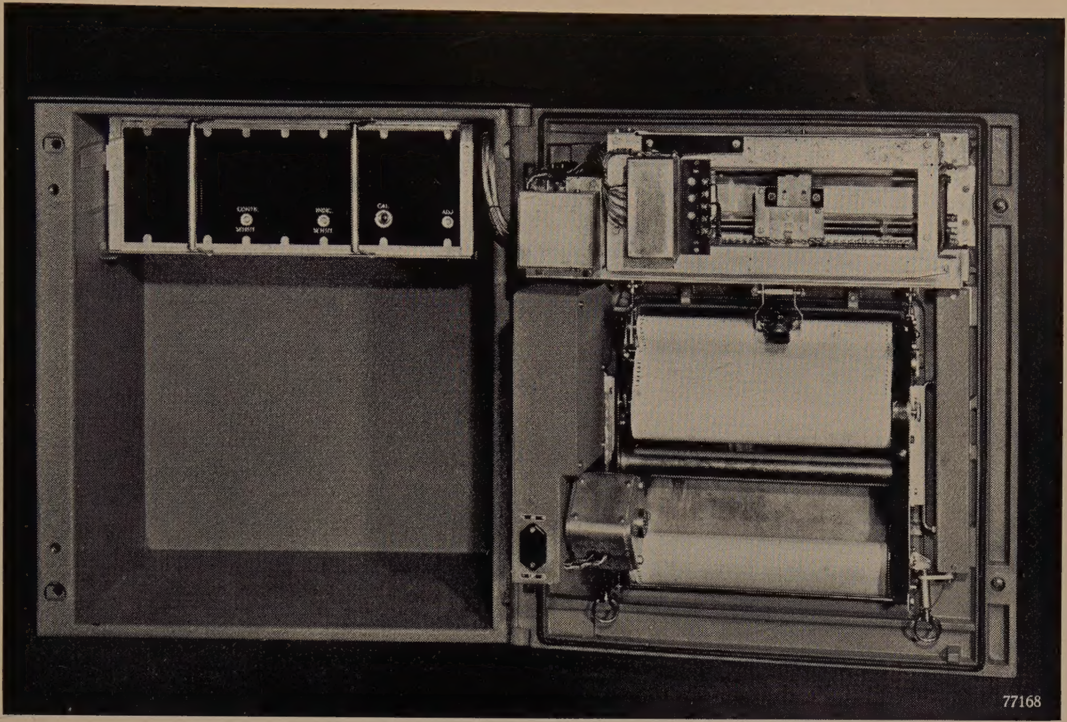

Fig. 10. Automatic recording potentiometer/bridge type PR 2000, showing recording mechanism. Top left: rack of amplifiers and supply units. Top right: in the opened cover of the instrument will be seen the slidewire, servo-motor and tachometer-generator, below which the recording mechanism is mounted.

In order to ensure the high degree of reliability demanded of equipment intended for industrial use, all the components are loaded far below their rated values; the use of components having only a limited life has been avoided.

Fig. 10 is a photograph of the instrument opened to show the interior. The front cover (at right) contains the slidewire, servo motor, tachometer-generator and recording apparatus, the electronic section (rack *E*, fig. 9) being mounted in the body of the unit (left). This rack is shown in detail in *fig. 11*, whilst *fig. 12* depicts one of the amplifiers removed from the rack.

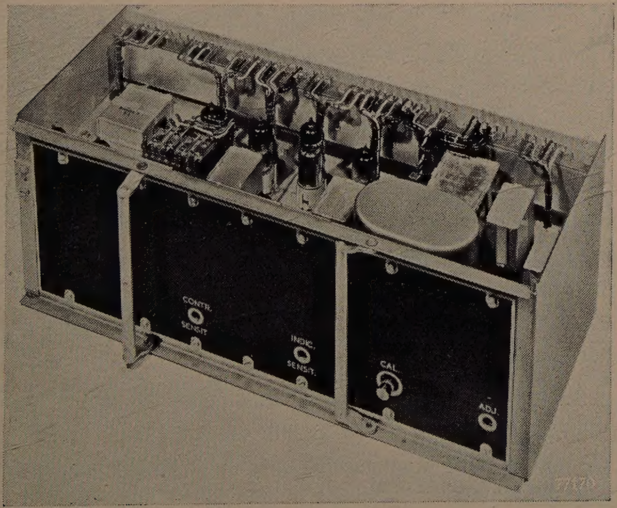

Fig. 11. Chassis with amplifier and supply units. All the leads are taken to a central connecting strip, to facilitate testing.

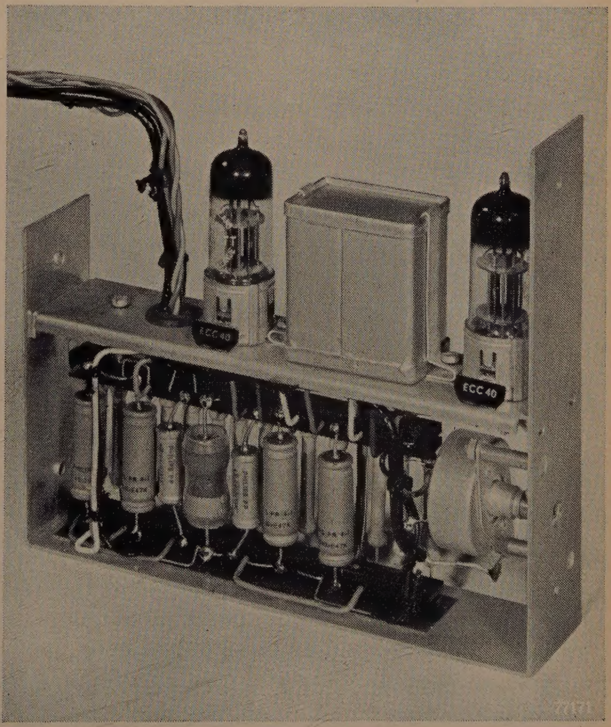

Fig. 12. One of the amplifier units. All the components are readily accessible.

To facilitate maintenance, all the main components, moreover, can be checked without any difficulty *in situ*, as all the principal leads are mounted on a central connecting strip on the rack (see fig. 11). The rack is connected to the other parts of the circuit through a line of plug sockets at the rear. All the components of each of the units are immediately accessible, once the chassis is removed from the rack (fig. 12).

The slidewire

As previously mentioned, the measuring accuracy is determined by the precision of location of the slidewire contact and the effective value of R_n, as well as the precision of the other resistors and the reference voltage. It is relatively easy to manufacture fixed resistors to a fine tolerance and with a high degree of stability, but with slidewires this is not such a simple matter. The total resistance of a slidewire can certainly be made quite constant, but it is equally necessary that its absolute value, as well as its fractional variation as a function of the position of the slider shall be carefully predetermined. (The maximum tolerance is 0.1 %.) In this way it is possible to change to a different measuring range without recalibrating the whole system, merely by changing the fixed resistors (unit B) and the scale. The slidewire R_n can then also be changed without necessitating recalibration of the scale. A fixed resistor is permanently connected across the slidewire, such that the equivalent resistance of the two is exactly 1000 Ω.

The cursor *W* is designed to carry the contacts of two slidewires simultaneously, thus making it possible to build up more complex circuits if required.

In order to secure a positional accuracy compatible with the measuring tolerance, the slidewire must have a high degree of linearity and must have a sufficient number of turns. In this instrument it is made with 1300 turns over a length of 260 mm, and has a linearity within ± 0.1 %. This means that the adjustment is accurate to about 0.1 mm.

Bridge supply voltage

For resistance measurements the bridge may be fed with alternating current at mains frequency. Sometimes, however, it may be necessary to employ direct current, for example, when the resistance to be measured is such a long way from the equipment that the capacitance of the leads would influence the result (these capacitances can, of course, be balanced out at the bridge, but it may be more convenient to avoid this complication by using direct current). When D.C. is used, the supply voltage is obtained from a rectifier with the necessary smoothing.

For D.C. voltage measurements, the bridge is used as a potentiometer. For this purpose the current through R_n must be of a constant and known value: it is therefore obtained from a source of voltage that is stabilized by means of a gas-discharge tube, whose operating voltage remains extremely constant throughout its life (type 85 A 1). The circuit is fed with a current of 1 mA (*fig. 13*) through a number of resistors, one of which (R_v) is variable, to enable the current to be adjusted to this value.

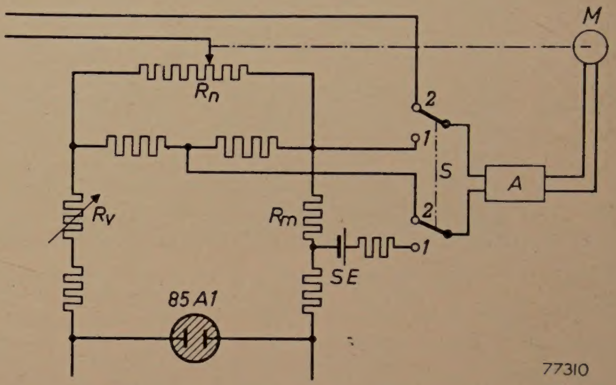

Fig. 13. Calibration of potentiometer. By means of the variable resistor R_v, the current for the potentiometer network is adjusted to 1 mA. This is verified by comparing the voltage across the resistor R_m (1018 Ω) with that of a Weston standard cell *SE*. For this operation the switch *S* is set to position *1*. With correctly adjusted current, the motor *M* does not operate.

Resistor R_m has a value of 1018 Ω, and in order to adjust the current to the exact value, the voltage across this resistor is compared with that of a Weston standard cell (1.018 V). This is effected by means of a switch *S* (fig. 13). When this switch is set to position *1*, the difference between the voltage across R_m and that of the standard cell *SE* is applied to the input of the amplifier *A*. If these voltages are equal, no voltage is applied to *A*, and the motor *M* is inoperative, but if a potential difference exists the motor revolves. This difference can be adjusted to zero by means of R_v, the indication of this being that the motor stops. The current is then at the correct value. Owing to the stability of the operating voltage of the tube 85 A 1, this calibration need not be made very frequently (e.g. once a month).

The amplifier

As electronic amplification can be effected most simply with A.C. voltages, the amplifier used is constructed as an A.C. amplifier. For the measurement of D.C. voltages, or for resistance measurements with the bridge operated on D.C., a converter is included between the measuring element circuit and the amplifier. This converter consists of a contact vibrator, the energizing coil of which is connected to a source of A.C. voltage at mains frequency. For electrostatic measurements, a vibrating capacitor is employed. For both resistance and D.C. voltage measurements, therefore, the frequency of the voltages to be amplified is 50 c/s.

To ensure high sensitivity, the greatest possible amplification is required, but in practice this is limited by the inevitable noise and pick-up; there is of course no object in increasing the gain to the point where the amplified voltages of these disturbances would be sufficient to start the motor or saturate the amplifier. The spurious voltages occurring in the first valve correspond to a voltage of 5 μV on the grid of this valve. For this reason it is desirable to adjust the amplification to such a value that only when a signal voltage of about 10 μV is applied to the grid of the first valve, will the motor start to move. (This assumes that there is no pick-up superimposed on the signal voltage, which might saturate the amplifier). By using a transformer before the input valve, the minimum input voltage at which the motor will operate is reduced to about 1 μV. The input transformer also has the effect of reducing the input impedance of the amplifier (without the transformer, this would be about 1 MΩ; with transformer it is roughly 1 kΩ). As the motor positively rotates at 100 V, the voltage gain required in the amplifier in then about 10^8.

When a vibrating capacitor is used, the input impedance can be very high, say 10^{12} Ω. Now, owing to this high impedance across the cathode and grid of the first valve, the spurious voltage produced in the amplifier — designed, it should be remembered, for industrial use — is considerably greater than the value mentioned above. For this reason, the amplification is so adjusted that the motor operates only on an input voltage of at least 300 μV.

The driving mechanism

For high accuracy it is essential that the position of the pointer in relation to the scale should agree exactly with that of the slidewire contact. Any backlash or flexibility in the transmission between slider and pointer would at once introduce errors. Such sources of error are avoided by mounting the pointer directly on the slider; in addition, the scale and the slidewire are rigidly mounted together (see *fig. 14*). The transmission between the motor and the cursor can thus in no way affect the accuracy of measurement.

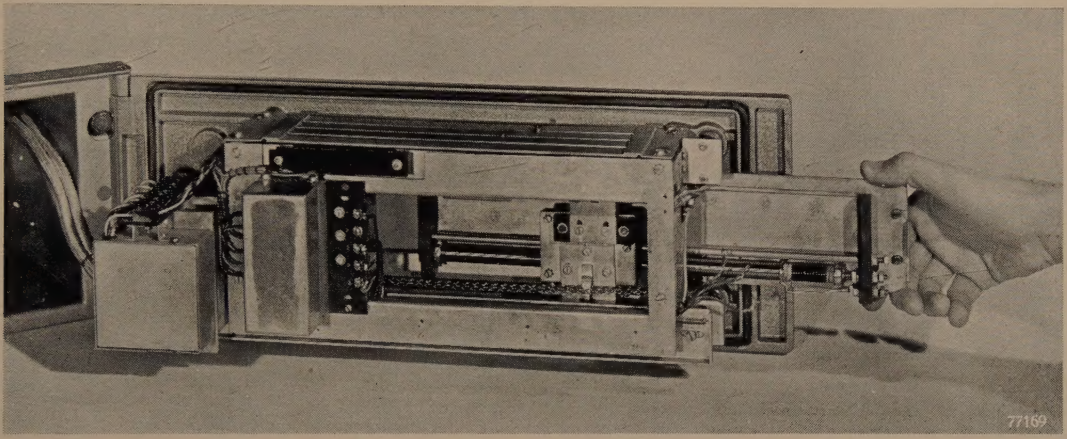

Fig. 14. The scale and slidewire are assembled as a single unit, as shown in this photograph of the non-recording version of the instrument.

The driving force must be at least high enough to overcome all sources of friction, and 300 grammes is adequate in this respect. To protect the cursor from being driven too forcibly against the end of of the scale by test signals beyond the actual measuring range, the potentiometer drive is of the slipping friction type.

The motor and generator

The motor is a two-phase induction motor with short-circuit rotor, as shown in diagram in *fig. 15*. One of the windings (A) is fed from the output amplifier, and the other (B), with a supply 90° different in phase, from the mains. When the point of balance of the measuring circuit is passed, the voltage delivered by the amplifier undergoes a phase shift of 180° and the motor reverses. To secure accuracy and stability in operation, a motor with a high starting torque is used.

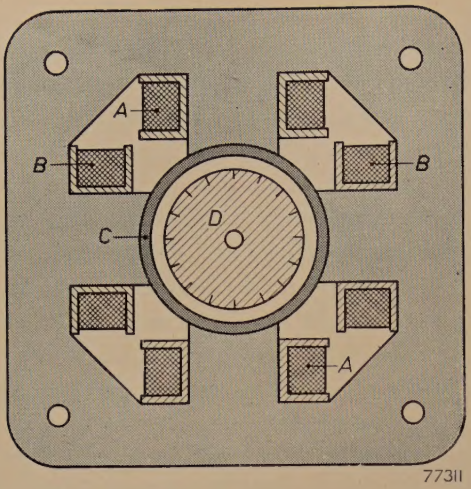

Fig. 15. Construction of the induction motor. Windings A are connected to the amplifier. Windings B are fed from the mains in such a way that the currents flowing in A and B differ in phase by 90°. An iron ring C distributes the magnetic fields set up by A and B so as to approximate to a rotating field. D is the short-circuit rotor.

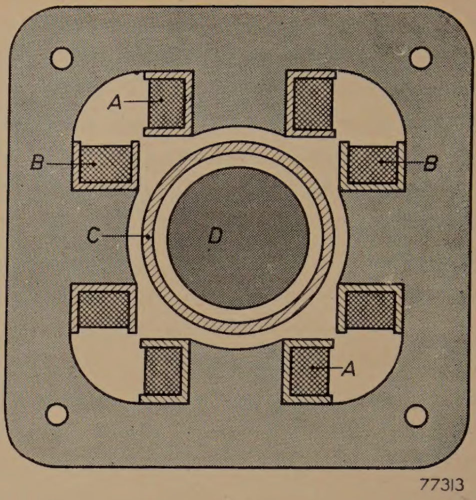

Fig. 16. Construction of the tachometer generator. Windings A are fed from the mains. When the aluminium rotor C is in motion, the magnetic field due to eddy currents in the rotor gives rise to a voltage in the windings B porportional to the speed of rotation. The output from the windings B is fed to the input of the amplifier section A_2 (see fig. 8).

Fig. 16 shows the principle of the tachometer generator. This also has two windings, one of which (A) is connected to the mains and the other (B) to the input of the amplifier section A_2 (see figs 8 and 9). The rotor consists of an aluminium cylinder (C) which revolves round a stationary iron core (D). When the rotor is brought into motion by the motor, a voltage is induced in winding B which is proportional to the speed of rotation. The frequency is the mains frequency and is therefore independent of the speed.

Reversal of the direction of rotation results in a phase shift of 180° in the voltage and, if the sign of the supply voltage has been correctly chosen, the phase relationship between the voltage delivered by the amplifier A_1 and that from the generator will be such that the latter provides a damping e.m.f. proportional to its speed. The ratio of the voltage delivered by the generator when stationary to that at full speed (approx. 2000 r.p.m.) is in the region of 1:1000. With the rotor stationary, the voltage induced in the winding B is therefore so small that it has a negligible effect on the result of measurement.

Summary. This article contains a description of an instrument for measuring D.C. voltages, resistances and impedances, of robust construction and high driving power. In conjunction with a suitable transducer, this instrument is suitable for the industrial measurement and recording of non-electrical quantities such as temperature, pressure, displacement, humidity, etc. The action of the instrument is based on the null principle which has many advantages over the direct-reading system, e.g. greater accuracy and higher sensitivity. The drawback of the null method, that an adjustment has to be made for each reading, is eliminated by using a servo-motor to effect the necessary adjustment automatically. The servo-motor, moreover, provides a considerable driving force; the setting time for full-scale deflection is about 1 sec. A tachometer generator coupled to the motor shaft provides a voltage which critically damps the motion, to prevent oscillation about the balance point (aperiodic damping).

AN APPARATUS FOR PROTECTION AGAINST DANGEROUS VOLTAGES IN WELDING EQUIPMENT

by F. H. de JONG and D. W. van RHEENEN. 621.791.735:621.316.722.3

In arc welding, the voltage requirements for good and rapid welding are, in general, in opposition to the demands of safety. A rather high no-load voltage is required which, in certain circumstances, may be dangerous to the welder. The apparatus described below gives complete protection to the welder, while in no way impairing the efficiency of the welding equipment.

Introduction

If alternating current is used for welding, this is usually furnished by a welding transformer. If direct current is used, a rectifier or a dynamo supplies the current. These diverse types of current source — here referred to under the general name of welding generators — have two electrical characteristics in common:

1) the output voltage drops considerably at increasing current;
2) the welding current at a voltage equal to the arc voltage can be adjusted between wide limits.

In *fig. 1* these typical properties are depicted for a welding transformer, by means of two characteristics, representing the output voltage V as a function of the welding current I. The one characteristic (*1*) refers to the adjustment using the highest welding current, the other (*2*) to the adjustment with the lowest welding current. Any characteristic between these two limiting curves may be obtained [1]). Other welding generators with similar voltage ranges, though with widely different current ranges, have similar characteristics.

The no-load voltage V_0 must be several times greater than the actual welding voltage (25-40 V), since otherwise the arc is difficult to start and will easily go out. On the other hand, it would be desirable to make V_0 as low as possible in order to minimize risk to the welder. The Netherlands Labour Inspectorate assumes that direct or alternating voltages up to 42 V will cause no fatal accidents in practice, but prohibits the use of higher voltages on exposed conductors. A welding generator with a no-load voltage of 42 V would, however, be of little use in practice for welding.

One is therefore compelled to work with no-load voltages with which danger to the welder is not entirely absent: as a rule, alternating voltages of about 80 V are used. Attempts have been made to reduce the danger by constructing the electrode holder in such a way that involuntary contact with live parts is practically impossible (*fig. 2*), or by prescribing the use of insulating gloves for the welder (to which, however, there are some practical objections).

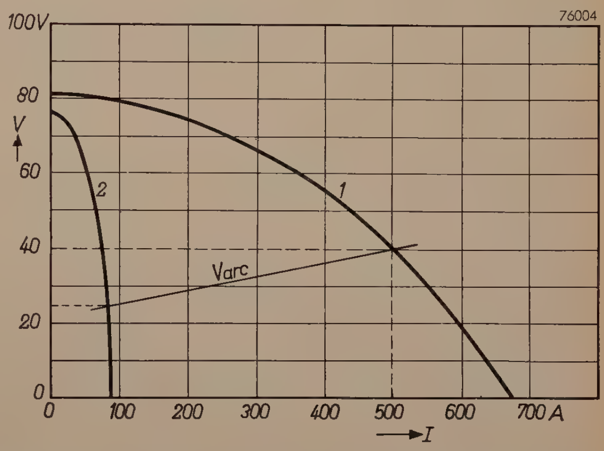

Fig. 1. Output voltage V as a function of the current I of an arc welding generator (here a Philips' welding transformer, type 3565). Curve *1* applies to the adjustment with the largest welding current, and curve *2* to that with the smallest. Continuous adjustment within these limits is possible. As the welding current is increased, the arc voltage rises from about 25 V up to about 40 V.

Such measures are by no means entirely satisfactory. Means have therefore been sought whereby the welding electrode and the electrode holder are isolated from dangerous voltages when the welding arc is not actually burning, in such a way that the welding operation itself is unaffected. The protective apparatus described below is distinguished from other devices on the market by the fact that it may be fixed to any welding generator whatsoever without causing any complications. It will presently be evident that in this appliance use is made of

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[1]) The way in which these characteristics are obtained in the Philips welding transformers and rectifiers has been described by H. A. W. Klinkhamer, Philips tech. Rev. 1, 338-345, 1936.

Fig. 2. Example of an electrode holder with insulated handle ("Safeweld" make).

the fact that a voltage of about 80 V is not dangerous unless one is exposed to it longer than a certain period of time. The Netherlands Labour Inspectorate has fixed this period at 0.2 sec., which includes a wide margin of safety.

Electric currents through the body are dangerous only when they cause so-called heart fibrilation. By this is meant a sudden and irregular contraction and relaxation of the heart muscles, which usually results in death. The mere feeling of a shock or irritation is not necessarily dangerous. Extensive investigations on this subject have been made by C. F. Dalziel of the University of California, Berkely. The following data are taken from one of his publications [2]).

Assuming the usual minimum value for the resistance of a current path through the body via the heart, viz. 500 ohms, it follows (from Dalziel's paper) that a voltage of 80 V, giving rise to a current of 160 mA, may be endured for one second without harmful results. The limit of only 0.2 sec, fixed by the Netherlands Labour Inspectorate, thus observes a wide margin of safety and at the same time allows some play in the actual value of the voltage.

Principle of the apparatus

The basic idea of this equipment is that, during the time when no welding takes place, the voltage V between welding electrode and the earthed piece of work is lowered to a harmless value by means of a voltage divider (R_1-R_2, *fig. 3*). As soon as welding is started, this voltage divider is automatically put out of circuit, so that then the full no-load voltage V_0 is available. The functioning will be clear from the simplified circuit diagram of fig. 3, and from *fig. 4*, which shows the voltage V and the position of various contacts as functions of time.

At the instant t_0, the welding generator (G, here a transformer), is connected with the mains via a switch (S_1). At first, V will then take the value $V_0R_2/(R_1+R_2) = pV_0$; the ratio is so chosen that pV_0 is a harmless voltage, e.g. 40 V. At the same time, the coil of an electromagnetic switch (S_2) in series with the transformer primary is energized. After a specified, very short delay period, this switch makes contact at the moment t_1, which short-circuits R_1. V now rises to V_0. This does not yet entail any danger, however, provided that, within 0.2 seconds, V has again dropped sufficiently. This is effected by means of a relay (*Re*) and a delay device (T), which are joined in parallel across the welding arc. At the instant t_0 the current had already begun to flow through the coil of the relay via the delay device. After a certain interval τ, at the instant t_2, the relay begins to move. In doing so it opens the contact (*1*), which is in series with the coil of the switch S_2. The latter therefore opens (at the instant t_2 if the delay of opening may be neglected), and V again decreases to pV_0. At this

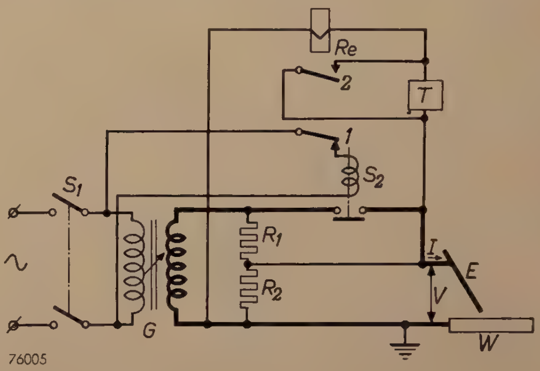

Fig. 3. Simplified diagram of the protective appliance. G welding generator, here represented as a transformer. W earthed piece of work. E welding electrode. R_1-R_2 voltage divider. S_1 mains switch. S_2 electro-magnetic switch. *Re* relay with break contact *1* and make contact *2*. T delay device.

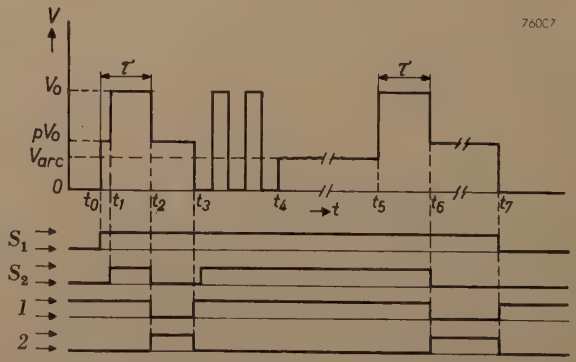

Fig. 4. Schematic representation of the r.m.s. value V of the voltage between welding rod and the work, as a function of the time t, in the circuit of fig. 3. V_0 = no-load voltage, pV_0 = voltage decreased by voltage divider. t_0 moment at which S_1 (fig. 3) closes. t_1 moment of S_2 closing contact. At t_2 after the delay time τ, relay *Re* is actuated. Between t_3 and t_4 an arc is drawn by tapping the welding rod on the work (arc voltage $V_{\rm arc}$). At t_5 welding is finished, at t_6 the relay is released and at t_7 the mains switch is opened.

Below the graph, the positions of the switches S_1 and S_2, and of the relay contacts *1* and *2* are shown.

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[2]) C. F. Dalziel, Dangerous electric currents, Trans. Am. Inst. El. Engrs. **56**, 579-585, 1946.

decreased voltage the relay remains attracted. In this position a second contact (*2*) short-circuits the delay device which is in series with the relay coil. The delay device is thus rendered inoperative, so that the relay can now work with practically zero delay. The maximum value of the delay time τ is fixed at 0.2 second, in accordance with the official safety requirements. The reason why τ may not be made indefinitely small will become apparent presently.

Welding may now be started. The welder brings the welding rod into contact with the piece of work (say at t_3), V consequently dropping to zero. As a result, the relay is released immediately and the contact *1* is again closed, so that the electromagnetic switch is energized and short-circuits R_1. The full short-circuit current of the generator can now flow through the welding electrode. On lifting the welding electrode, the arc will be started either immediately, or after few taps. From now on, V is equal to the arc voltage (25 to 40 V), i.e. not large enough to operate the relay again. As welding proceeds, it sometimes occurs that the arc is broken momentarily. For a few cycles the welding current is then zero and the voltage is therefore equal to the no-load voltage. This should not cause the relay to open: if it did, the electromagnetic switch, because of its rapid response, would open perhaps just when the arc was struck again. The interruption of the full welding current, which may amount to hundreds of ampères, may seriously overload the contacts of the switch S_2. This is one of the reasons why a certain delay must be associated with the relay *Re*. The delay time required for this proves to be shorter than the 0.2 sec allowed for reasons of safety. The delay can therefore be chosen so as to meet both requirements.

As it happens, this delay has an important technical advantage in welding. If the momentary interruptions of the welding current were to result in the opening of the contacts of S_2, the voltage V would drop again to pV_0, and the welder would have some difficulty in starting the arc again, and faulty welds might result. The delay on the relay *Re*, however, prevents the protective device from reacting to such short interruptions, and the welder is therefore not hindered in any way.

It is assumed that at t_5 (fig. 4), the welder finishes his work. He lifts the electrode from the work, so that the welding arc is broken and the voltage rises to V_0. After the delay time τ the relay will be actuated again (at t_6), the contact *1* opens, the switch S_2 opens its contacts (no current at present through these contacts), and the voltage V drops to the safe value pV_0.

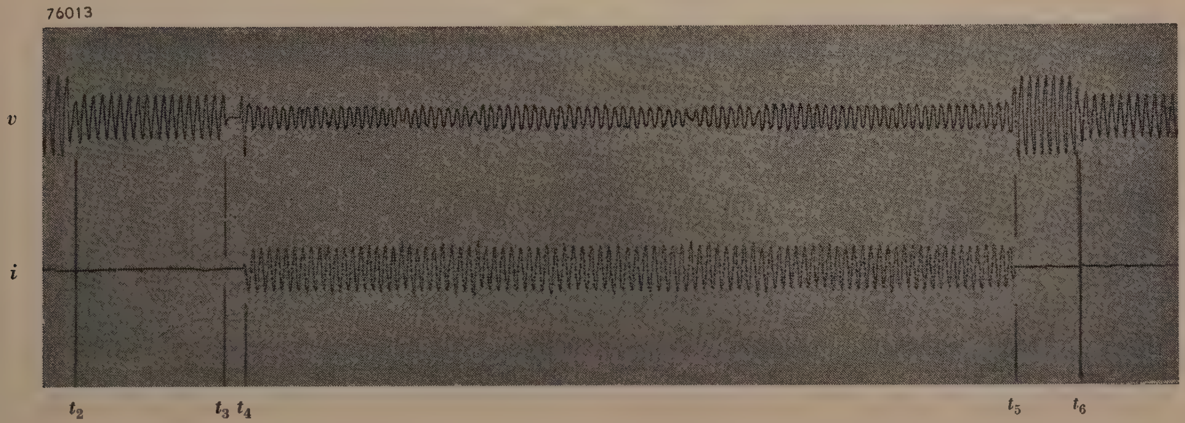

Fig. 5. Oscillograms of the voltage on the welding rod and the welding current (instantaneous values v and i). The instants t_2 . . . t_6 correspond to those in fig. 4. The interval τ from t_5 till t_6, covers 8 cycles of the mains voltage (frequency 50 c/s), i.e. <0.2 sec. In about 1 cycle after tapping, the current is established.

The various operations just described can be found in the oscillograms of *fig. 5*, which show the instantaneous values of the welding current i and of the arc voltage v as functions of time. It can be seen that the interval τ, during which the full no-load voltage is present, lasts for only 8 cycles of the mains voltage (frequency 50 c/s), i.e. less than 0.2 sec. The oscillogram also shows that when the voltage becomes zero (welding rod in contact with the work, e.g. at the beginning of the welding period), the non-delayed relay quickly releases, and in 1 to 1.5 cycles (0.02 to 0.03 sec) the welding current will again begin to flow.

Construction

In fig. 3 the relay *Re* is for simplicity shown as an A.C. relay. A relay working on direct current, however, has certain advantages, especially if it is to be given a specific delay time. A direct current relay is therefore used in the present equipment. It is fed from a small full-wave rectifier (bridge circuit, connected as shown in *fig. 6*) which takes the place of the resistor R_2 (fig. 3).

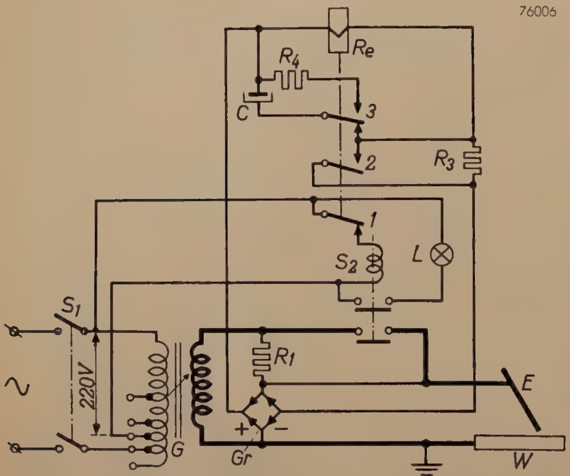

Fig. 6. Complete diagram of the protective device. *Gr* small selenium rectifier. R_3 resistor and *C* capacitor which together form the delay device (*T* in fig. 3). R_4 resistor, and *3* contact for discharging the capacitor. *L* pilot lamp. For the meaning of the other letters, see fig. 3.

A delay for the relay is obtained by means of a capacitor (*C*) in parallel with the relay coil, and a resistor (R_3) in series with this parallel connection. The delay time τ then depends on the values of *C* and R_3. The delay is removed by short-circuiting the resistor R_3 through the relay contact *2* and by simultaneously breaking the circuit containing the capacitor by means of a third relay contact (*3*). The same contact provides for the discharge of the capacitor through a resistor (R_4).

A further protective feature of this instrument is a pilot lamp which shows red as long as the electromagnetic switch (S_2) is closed, i.e. whenever a dangerous no-load voltage is present. The lamp will flash when the mains switch is first closed, and thereafter burns only while welding takes place. If some mechanical or electrical fault should cause the switch S_2 to remain closed when welding has finished, this would also be made known by the red light.

The interior of the apparatus (type PE 3100), showing some of the components, is shown in *fig. 7*.

Some further remarks should be made concerning the electromagnetic switch. This may be used for welding currents up to 500 A. For such a large current the switch is very small, due primarily to the fact that it breaks the circuit only when zero current is flowing, but also due to the manner in which the circuit is closed. A well-known objection to many electromagnetic switches is the rattle of the contacts which occurs on closing. This results in pitting and deterioration of the contacts. This is prevented on the switch used in this equipment, by causing the moving contacts (*4*, *4'*, fig. 7) to first touch the preliminary contacts (*5*, *5'*), which consist of flat limp springs so that no rattling occurs and the circuit is closed without interruptions. Only then do the moving contacts touch the main contacts (*6*, *6'*). Any rattling which now occurs is of no consequence, since the preliminary contacts remain closed. The latter, in the course of time, suffer some damage from the continual closing of the circuit, but they are easily renewed, as can be seen from fig. 7. The main contacts and

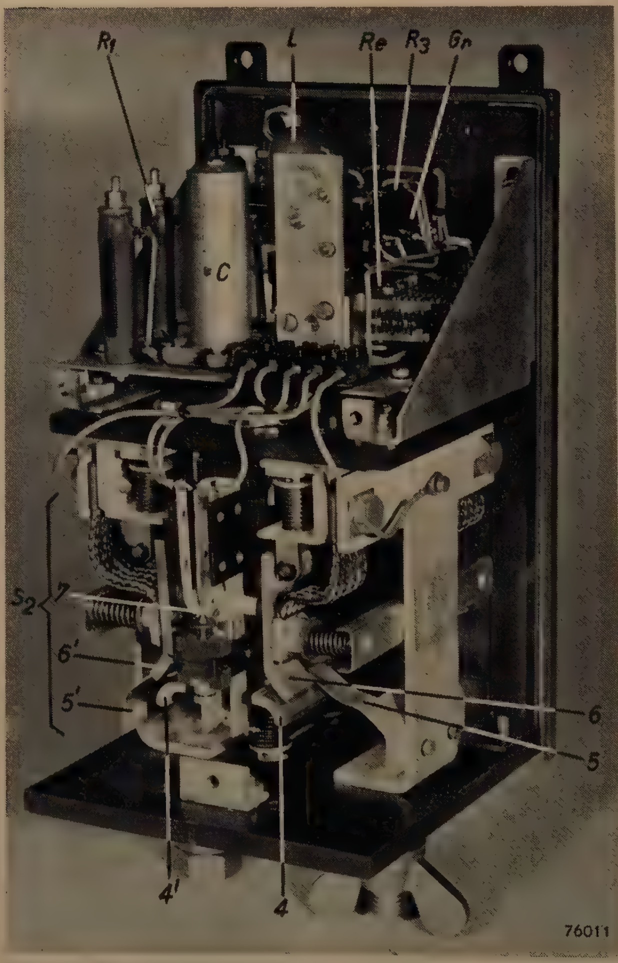

Fig. 7. The protective appliance type PE 3100 (cover removed). *4*-*4'* moving contacts of the electromagnetic switch S_2. *5* and *5'* preliminary contacts, *6* and *6'* main contacts, *7* auxiliary contact for the pilot lamp *L*. For the meaning of *Re*, *C*, R_1, R_3 and *Gr*, see fig. 3 and fig. 6.

the moving contacts are made of a chrome copper alloy that will stand a good deal of wear and tear. Switching tests showed that after 100 000 operations at 500 A, the latter contacts were still sound, and that the preliminary contacts showed some signs of burning, but not sufficient to merit their replacement.

Application

From the above description it will be clear that this protective appliance may be used with any type of welding generator without involving any major modifications to the latter. In general, with other protective devices, this is not the case; usually the no-load voltage is decreased by means of a voltage divider attached to the *primary* side of the welding transformer or rectifier, consisting of the primary coil of the transformer and a series choke coil, which is automatically short-circuited during welding. This type of voltage divider always has a rather low impedance. The protective appliance described here, with its high-impedance voltage divider attached to the secondary side, has a number of advantages, viz:

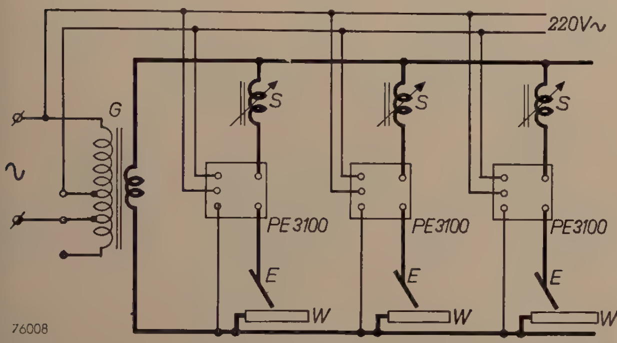

Fig. 8. Connection for multiple welding with common transformer (G). The dropping of the V-I curve (of fig. 1) is in this case only to a slight extent caused by the transformer; it is mainly obtained by means of choke coils (S), of which one has been fitted to each welding circuit (work W, welding rod E). The self-induction of the choke coils is adjustable, for regulating the welding current. The protective applicane PE 3100 is suitable for such an installation, as shown in the diagram.

a) The large choke coil necessary for most protective appliances, with tappings for different mains voltages, is replaced in this apparatus by a small resistor (R_1, fig. 7).
b) Since the primary winding of the welding generator is not concerned in the protective device, no changes are necessary in the connections of power factor condensers.
c) Again, since the primary winding of the welding generator is not concerned, the device may be used for multiple welding with a common transformer, as often used in shipbuilding. The arrangement in this case is shown in the circuit of *fig. 8*; it can be seen that in this case a protective appliance connected to the primary side would not be feasible.
d) Owing to the high impedance of the voltage divider (R_1-R_2, fig. 3), even a somewhat deficient contact between the welding rod and the work will be sufficient to lower the voltage V such that the relay opens and the switch S_2 closes. With a voltage divider of low impedance, however, a good contact would be necessary: a rusty piece of metal would have to be previously cleaned in order to ensure that S_2 closed and rendered the voltage divider inoperative.

To connect the Philips protective appliance to a welding generator, only the following connections are necessary:

1) Connecting the contacts of the electromagnetic switch S_2, in series with the welding electrode. This involves only external connections, as can be seen from *fig. 9*, which shows the appliance mounted on a welding transformer.

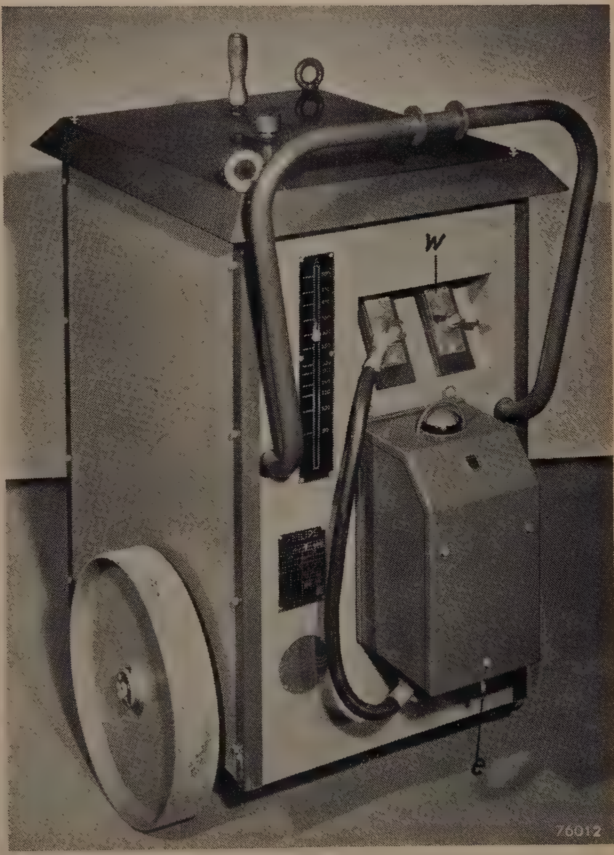

Fig. 9. The protective appliance PE 3100 mounted on a welding transformer. The work has to be connected to the terminal w, the welding rod to the terminal e.

The welding current may be adjusted by means of the handle on top of the transformer and can be read on the scale by the side of the terminals.

2) Making a connection with the earthy generator terminal (w), with which the work is connected (*fig. 10*).
3) Connecting the unit with a supply of 220 V alternating voltage. Even if the mains voltage has another value, the required voltage can usually be obtained from tappings on the primary side of the welding transformer, the rectifier transformer, or the motor driving the dynamo.

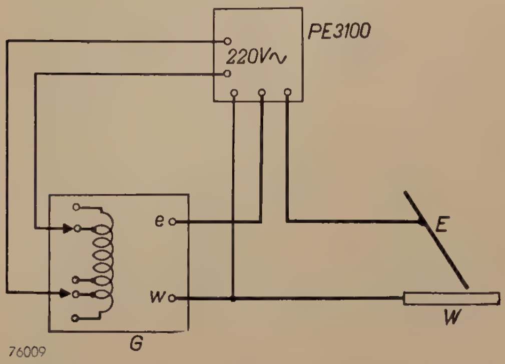

Fig. 10. Connection of the protective appliance PE 3100 to a welding generator. The only connections necessary are:
1. Two leads, one from the live transformer terminal to the apparatus and one from the apparatus to the welding rod.
2. A connection from the earthy terminal (w) of the transformer, with which the work (W) is connected.
3. Supply voltage of 220 V A.C. (from the mains side of the welding generator G).

Summary. The no-load voltage of most welding generators has a value of about 80 V. In certain circumstances this may be dangerous to the welder, but it cannot be decreased without adversely affecting the welding efficiency.

A protective appliance is described which eliminates the danger without affecting the welding efficiency. It is based on the principle of a voltage divider, which lowers the voltage between welding rod and the earthed work to a non-dangerous value while no welding is taking place, but which cuts out automatically as soon as welding is started, so that the full no-load voltage becomes available. This operation is done by an electromagnetic switch fitted with a delay time (0.2 sec, in accordance with the requirement of the Netherlands Labour Inspectorate). The delay time ensures that, while the switch will always cut out when no current is flowing, the welder will not be hindered by short interruptions of the welding current. The voltage divider itself is connected to the secondary winding of the welding generator and has a high impedance. This has a number of advantages against the more usual primary-connected voltage divider, which necessarily has a rather low impedance. Thus the appliance is easily mounted on any welding generator (transformer, rectifier, dynamo), without any changes in the connection of power factor condensors. The high impedance of the voltage divider ensures that the appliance works well even when the contact between the welding electrode and the work is not particularly good, whilst its connection on the secondary side permits the appliance to be used for "multiple welding". The appliance described (PE 3100) is suitable for welding currents up to 500 A.

A SIGNAL GENERATOR FOR THE TESTING OF TELEVISION RECEIVERS

by B. W. van INGEN SCHENAU.

621.396.615.17:621.397.62.08

The increasing number of TV receivers has made it necessary to develop methods for the rapid rectification of faults. Particularly useful for this purpose would be an easily portable generator, capable of producing all the signals necessary for this form of trouble-shooting; with the aid of such a generator tests could be made outside the normal transmission period of TV transmitters.

The generator described below produces the various signals required for the rapid tracing of a large number of faults occurring in receivers, both in the video and audio channels.

The various television standards

Considered as a whole, a television receiver is a fairly complicated piece of apparatus, and it is therefore hardly surprising that faults develop from time to time. A radio mechanic, called in to deal with a fault, will in most cases be able to do little as long as no normal TV signal is available. Since in most countries the TV transmitters are on the air for only a few hours per day, there is a great demand for a generator capable of supplying all the desired signals. Such a generator should be portable to facilitate use on the spot. The generator about to be described *), type GM 2887 (*fig. 1*), satisfies this requirement: the weight is approximately 7 kg ($15^1/_2$ lb), and the dimensions are $335 \times 220 \times 165$ mm (13″ × $8^1/_2$″ × $6^1/_2$″).

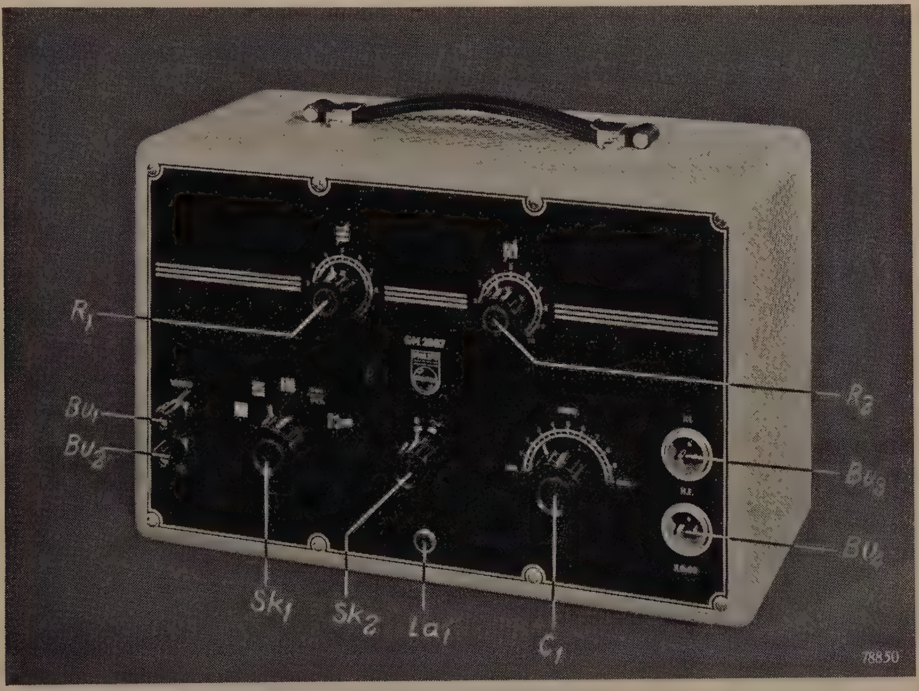

Fig. 1. Signal generator type GM 2887. Various video signals and an audio signal can be selected with the switch Sk_1 and the knobs R_1 and R_2. The carrier-wave frequency can be varied with knob C_1. The video signal appears at terminals Bu_1-Bu_2, the modulated H.F. signal at sockets Bu_3 and Bu_4. Sk_2 mains switch, La_1 pilot lamp.

The signals produced should obviously conform to the TV standard of the country in which the generator is to be used. Different standards prevail in the various countries. *Table I* shows the main characteristics for so far as our purpose is concerned. It comprises (a) the "International" standard, suggested some time ago by the Comité Consultatif International des Radiocommunications (C.C.I.R.) at Geneva, and adopted by a large number of countries 1)), (b) the British, (c) the American 2)) and (d) the French standard.

The differences between these standards are such that a single version of this signal generator would not be suitable for all four systems. For this reason the generator GM 2887 is produced in four models, designated by the letters A, B, C and D. The main data are given in *table II*.

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*) The development of this generator was initiated by Mr. H. C. Wardenaar.

1) These countries are: Argentina, Austria, Denmark, Finland, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, Turkey, West-Germany, and Yugoslavia.

2) In use in the U.S., Canada and various countries of Latin America. The American as well as the International standard are used in Brazil.

Table I. Data on the television standards of various countries. f_s = frequency of the sound carrier-wave. f_v = frequency of the video carrier-wave. f_r = frame frequency. T_l = time interval between the beginning of one line and the beginning of the next. A.M. = amplitude modulation. F.M. = frequency modulation.

	International standard [1] (C.C.I.R.)	British standard	American standard	French standard
Picture modulation *)	negative	positive	negative	positive
Low. freq. band (Mc/s)	41- 68	41-68	49- 88	—
High freq. band (Mc/s)	174-223	—	174-216	174-216
f_s-f_v (Mc/s)	+5.5	—3.5	+4.5	—11.15
f_r (c/s)	50	50	60	50
Duration of frame-sync. pulse	$3T_l$	$4T_l$	$3T_l$	$0{,}4T_l$
Duration of frame blanking	$(19\text{-}31)T_l$	$14T_l$	$(13\text{-}20)T_l$	$41T_l$
Number of lines	625	405	525	819
Duration of line-sync. pulse	$0.09T_l$	$0.10T_l$	$0.08T_l$	$0.05T_l$
Duration of line blanking	$0.18T_l$	$0.15T_l$	$0.16T_l$	$0.16T_l$
Sound modulation.	F.M.	A.M.	F.M.	A.M.

*) See later (fig. 3).

Table II. Main characteristics of the four models of the GM 2887 signal generator.

Model	Number of lines	Line freq. c/s	Frequency band Mc/s	Picture mod.	Sound modulation	Standard
A	625 525	15 625 15 750	40- 80	neg.	F.M.	International American
B	405	10 125	40- 80	pos.	A.M.	British
C	625 525	15 625 15 750	170-230	neg.	F.M.	International American
D	819	20 475	170-230	pos.	A.M.	French

As will be shown later, with the aid of the generator GM 2887, a television receiver can be tested for the following:

1) synchronization,
2) linearity of the horizontal and vertical deflection,
3) correct connection of the deflection coils,
4) step-function response of the video amplifier,
5) sensitivity of the receiver (very roughly),
6) functioning of the video-frequency stages,
7) sound channel.

Signals produced by the generator and their use

The generator contains an *LC* oscillator, the frequency of which can be continuously varied (either between 40 and 80 Mc/s, or between 170 and 230 Mc/s) by means of knob C_1 (fig. 1), which operates a variable capacitor. The knob is not provided with a frequency scale, as this would have raised the price considerably, and in nearly all cases it is sufficient to test each channel to which the receiver can be tuned, without the necessity of knowing whether the frequency limits of these channels are correct.

The oscillator produces a voltage of 2×(25-50) mV, symmetrically disposed with respect to earth [3]). The full voltage appears across the output socket Bu_3, whilst a value attenuated by a factor of approximately 1/50, appears at the socket Bu_4. The signal is conveyed from either of these sockets to the input of the receiver by means of a screened cable, supplied with the generator.

The cable has a characteristic impedance of 80 ohms, a value well adapted to many receivers. There are, however, also receivers with an input impedance of 300 ohms; for these the small box at the end of the cable (*fig. 2*) must be provided with a network giving the exact matching.

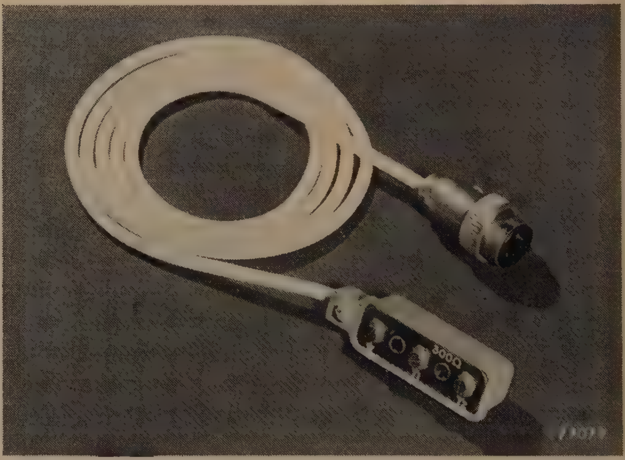

Fig. 2. Cable for connecting the generator to the TV receiver. The terminal box in the foreground contains a matching network for receivers having an input impedance of 300 ohms.

Five different signals can be modulated on the oscillator voltage; a choice of these is given by the switch Sk_1 (fig. 1). In the positions *1*, *2*, *3* and *4* of this switch — the video positions — the oscillator voltage is modulated with synchronizing signals and certain picture signals. In position *5* — the audio position — it is modulated either in frequency (models A and C) or in amplitude (models B and D) with an audio-frequency voltage, for the testing of the audio sections of the receiver.

With models A and C the video modulation is negative, whilst in models B and D it is positive.

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[3]) This is not the case with model D, since the majority of French receivers have an asymmetrical input.

"Positive" and "negative" modulation are explained in *fig. 3*. The following discussion of the various output signals of the generator will be restricted to negative modulation.

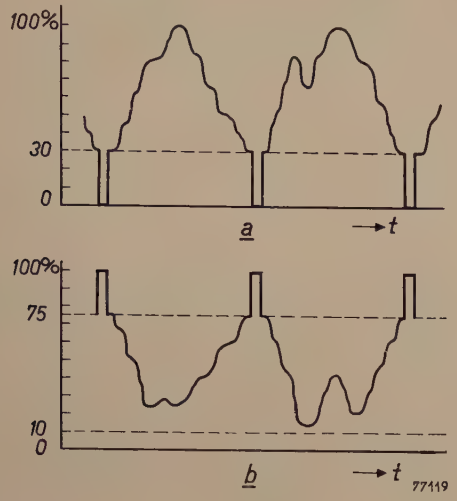

Fig. 3. *a*) Positive, *b*) negative modulation. The white level, the black level and the synchronization peaks lie respectively at 100%, 30% and 0% of the signal strength, with positive modulation, and at 10%, 75% and 100% with negative modulation.

1) *Synchronization*

With the switch Sk_1 at position *1*, the output voltage at Bu_3 has the shape shown in *fig. 4a*. The square peaks are the line synchronization signals. On either side of this, the signal is for a moment at the black level: the prescribed "front porch" and "back porch". These "porches" and the line synchronization pulse together form the line blanking signal (fig. 4*b*); this suppresses the beam during flyback. In the case shown in fig. 4*a*, the high frequency voltage present between the line synchronization signals has a small amplitude which corresponds to "white".

A frame synchronization signal with a frequency equal to the mains frequency is also given by the generator (not shown in fig. 4*a*); this signal too is accompanied by a front and back porch, so that vertical flyback is also suppressed.

With the signal shown in fig. 4*a* fed to the aerial terminals of a TV receiver, the horizontal and the vertical deflection should be synchronized with the generator so that the flyback becomes invisible, and the screen appears uniformly white.

2) *Linearity of the deflections*

If the receiver synchronization is satisfactory, the switch Sk_1 is set to position 2. In this position the generator gives a signal (*fig. 5a*) such that a series of white lines are traced but suppressed at regular intervals, so that horizontal white bars appear on the screen (*fig. 6a*). If these bars are not of equal width, then the vertical deflection is not linear. The majority of sets have a trimmer with which the linearity can be adjusted.

In position *3* of switch Sk_1 the output signal has the shape shown in fig. 5*b*. This gives rise to lines which are blacked out at regular intervals, forming a series of vertical bars on the screen (fig. 6*b*). Any differences in width between these bars show that the horizontal deflection is not linear and needs adjustment.

The horizontal and the vertical bars are combined when the switch Sk_1 is put in position *4*. Fig. 5*c* shows the shape of the signal, and fig. 6*c* is a photograph of the pattern which should appear on the screen.

3) *Correct connection of the deflection coils*

When a repair is made, it sometimes happens that the connections of the deflection coils are inadvertently reversed. This would give a reversed picture (top and bottom reversed, or left and right, or both). Owing to the symmetry of the bars, such reversal cannot be detected. A means of detecting this fault is given by the fact that the *number* of bars is continuously variable (from 6 to 10) by means of the control knobs R_1 (horizontal bars) and R_2 (vertical bars) (fig. 1). If the number of horizontal bars is increased, then the additional bars should appear on the screen from the bottom upwards; when the number of vertical bars is increased, the bars should appear from the right-hand side.

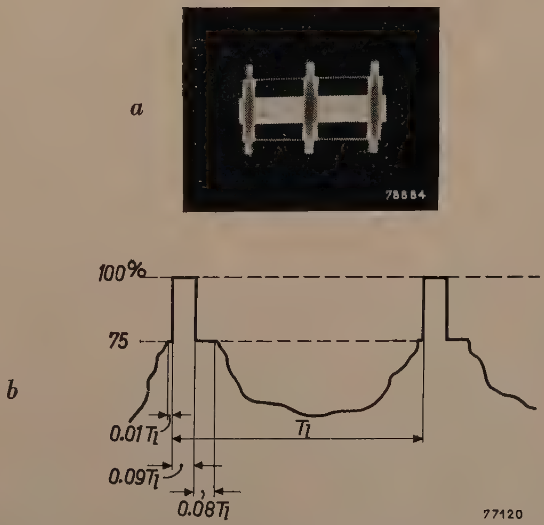

Fig. 4. *a*) Oscillogram of the high frequency output voltage. The line blanking signals can be seen, with the picture signal "white" (negative modulation) in between. *b*) Line synchronization pulses, with front porch on the left and back porch on the right (both at black level), and an arbitrary picture signal (negative modulation). The specified times apply to the International standard.

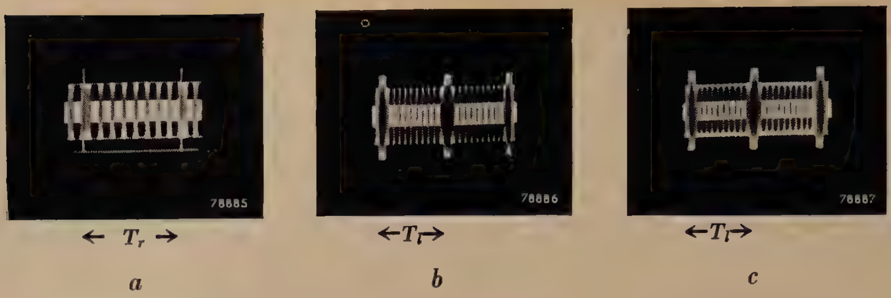

Fig. 5. Oscillograms of the high frequency output voltage (all with negative modulation). *a*) Horizontal bars, *b*) vertical bars, *c*) horizontal and vertical bars. T_r frame period, T_l line period.

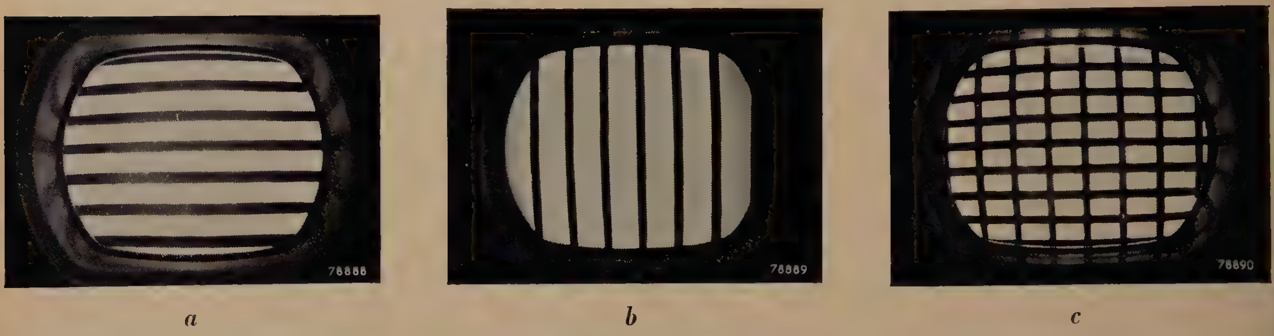

Fig. 6. Images on the picture tube, corresponding to the signals of fig. 5. *a*) Horizontal bars, *b*) vertical bars, *c*) horizontal and vertical bars.

Additional bars appearing from above or from the left are an indication that the vertical or horizontal deflecting coils have been incorrectly connected.

4) *Step function response*

The bars should have a uniform brightness over their entire width but deviations from this can occur, an example of which is given in *fig. 7a*. Here the receiver distorts the square pulses of the video signal into "sagging" pulses (fig. 7*b*) as a result of attenuation of the low frequency components. The cause of this may be a disconnected coupling capacitor in the receiver, so that only the very small capacity between the ends of the two wires is operative.

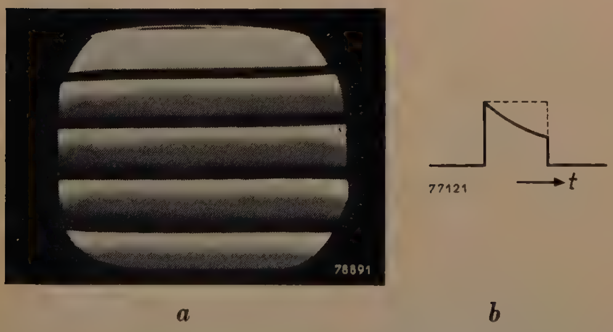

Fig. 7. *a*) Horizontal bars with non-uniform brightness caused by a square pulse (dotted in *b*) in the receiver being distorted to a "sagging" pulse (full line).

Even in the absence of a fault in the receiver, a brightness variation can exist in the vertical bars, viz., if the signal generator is badly tuned to the receiver. The frequency of the generator or of the receiver should therefore be adjusted so that the brightness is as uniform as possible before any conclusions may be drawn with regard to faults in the receiver.

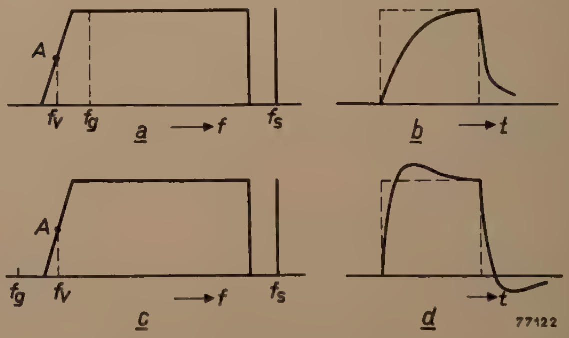

Fig. 8. *a*) Frequency characteristic of one channel of a TV receiver conforming to the CCIR (International standard). The video carrier-wave frequency f_v must be equal to the frequency corresponding to the centre *A* of the left flank. f_s audio carrier-wave frequency. The carrier-wave frequency f_g of the generator is here (*a*) shown higher than f_v, with the result that a square pulse in the receiver is distorted as in (*b*). *c*) As *a*), but with $f_g < f_v$, which results in a square pulse being distorted as in (*d*).

Fig. 8 shows why incorrect tuning gives rise to non-uniform brightness in the vertical bars. Fig. 8*a* shows an idealized frequency characteristic of one channel of a receiver conforming to the International standard. The video carrier-wave frequency f_v should be equal to the frequency corresponding to the centre *A* of the left flank of the curve; the low frequency video components sent out by the transmitter in two side-bands then add to produce a signal as strong as that of the higher frequency video components, transmitted only in the upper side-band. If now the carrier frequency f_g of the signal-generator lies somewhat above f_t, then there will be a surplus of the lower frequency video components in the receiver, with the result that a square pulse will be distorted as drawn in fig. 8*b*, and the brightness will gradually increase from left to right. If f_g should lie somewhat below f_t (fig. 8*c*), then there will be a deficiency of the lower frequency components, and the square pulse will be distorted by "overshooting" (fig. 8*d*), with a corresponding brightness variation.

5) Sensitivity

By connecting the receiver to the socket Bu_4 (fig. 1), where the voltage is only 1/50 of the voltage at Bu_3, a rough impression of the sensitivity of the set can be attained. With this attenuated input voltage, the synchronization should be maintained and the pattern of bars should remain well visible, although the image may possibly show signs of "noise" (similar to swirling snow flakes).

6) Video signal

It may be desired to check the functioning of the output valve of the video section and the picture tube, independent of any faults which may be present in earlier stages.

For this purpose the video signal of the generator, of amplitude approx. 1 volt at the terminals Bu_1-Bu_2 (fig. 1), can be fed directly to the output valve concerned.

Use can also be made of these terminals to check the generator itself, by connecting it to an oscilloscope. In order to give a true representation of the video signal, the oscilloscope used must be capable of giving a good reproduction of pulses of duration 1/4 μ sec. (This requirement is met by the oscilloscope GM 5653.)

7) Sound

It has already been mentioned that with the switch Sk_1 in position 5, the audio channel of the receiver can be checked. The oscillator is then modulated (in frequency or in amplitude) with an audio frequency signal, viz. the voltage supplied by the generator for the horizontal bars. This is a square-wave voltage with a fundamental frequency variable from about 300 to 500 c/s. In order to make the sound less unpleasant to the ear, the square shape is rounded off slightly by a simple filter, and the frame synchronization signal (pulses of mains frequency) is kept away from this voltage.

Economizing in weight by simplification

The present television standards, however much they may differ from each other, have interlaced scanning in common: this implies that the line frequency is an odd multiple of the frame frequency [4]). Now, to derive the frame frequency from the line frequency by frequency division involves somewhat complex apparatus. Furthermore, with all TV standards, the synchronization signals, especially the frame synchronization signals, are fairly complicated in shape [5]). The generation of these signals likewise requires considerable equipment. These are all combined (together with a high frequency oscillator and a small oscilloscope) in a standard generator (type GM 2657) which has been developed for laboratory purposes. For use in the home of the set-owners and in the repair shop, however, such an apparatus is too bulky, too heavy and too expensive. In the design of the portable signal generator GM 2887, dealt with here, the aim has been to drastically cut down on dimensions, weight and price without in any way impairing its usefulness for the specific purpose for which it was intended.

This aim has been achieved largely by abandoning the demand for a fixed ratio between line frequency and frame frequency, so that the frequency dividers could be dispensed with. The result is, of course, that now the picture lines are not absolutely stationary but shift arbitrarily in the vertical direction. A slight deterioration of the picture quality results from this, although with the simple bar patterns this is hardly noticeable and in no way impedes the tracing of faults.

Dispensing with the interlacing has the effect that the line synchronization signal can be simplified since the equalizing pulses are then unnecessary and can therefore be omitted (equalizing pulses are extra line pulses which are necessary in systems with interlacing because there the frame synchronisation signal occurs alternately at the end of a line and in the middle [6])).

The number of valves has been kept down, not only by these simplifications, but by the use of double valves: the signal-generator has nine triode-pentodes ECL 80 and two double triodes ECC 81, and further, one rectifier AZ 41 and one neon tube, a total of 13 tubes. The total D.C. consumption is

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[4]) See, e.g. Philips tech. Rev. **10**. 307, 1949, or W. Werner and F. Kerkhof, Television (Philips Technical Library 1952) pp 4 and 5.

[5]) For the synchronization signals conforming to the international standard, see "Standards for the International 625-line black-and-white television system", Sub-group Gerber, CCIR, Geneva, Oct. 1950, or Philips tech. Rev. **13**, 313 (fig. 1), 1952. For those conforming to the British and the (then) French standards, see Philips tech. Rev. **10**, 365 (fig. 1), 1949. See also, International Television Standards, Wireless World **48**, 296-297, Aug. 1952.

[6]) See, e.g. Philips tech. Rev. **13**, 313 (fig. 1), 1952.

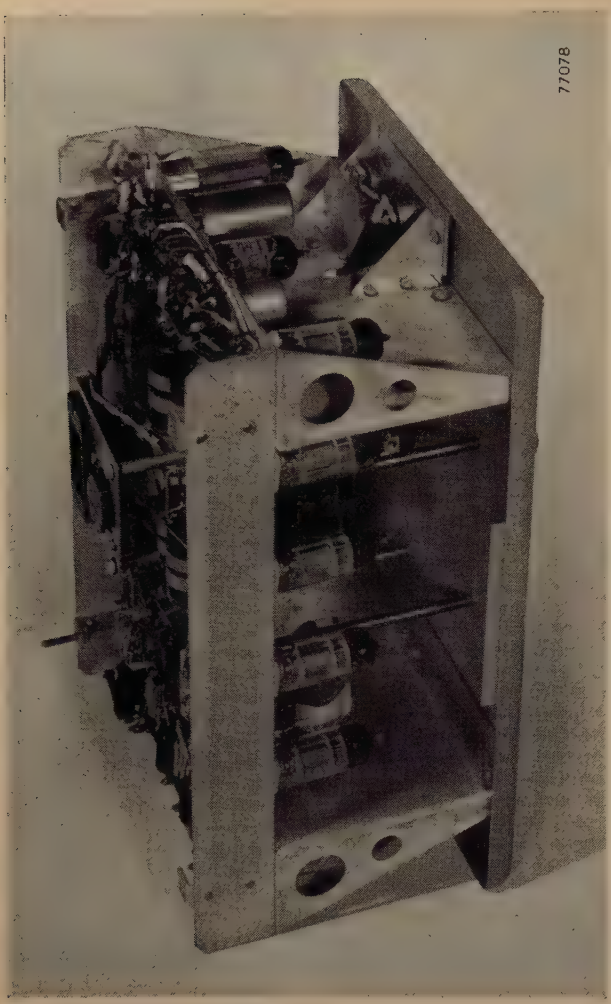

Fig. 9. The interior of the generator GM 2887. The heaviest component, the transformer, is located in the middle with the valves around it.

low (45 mA), and the total power taken from the mains is only about 40 W, so that a small and light transformer is capable of supplying the apparatus.

Fig. 9 gives a view of the interior. To facilitate carrying, the heaviest component, the transformer, is mounted in the centre. The tubes are located around it, and are thus easily accessible.

Description of circuits

Block diagram

Fig. 10 is the block diagram of the generator. On the right-hand side of the diagram is the modulator (*Mod*) in which the high frequency voltage from the oscillator (*Osc*) is modulated by the video signal originating in the unit *Vid*. The unit *Vid* is an "adding stage" in which the picture signal, supplied by *P*, and the synchronisation signals from *Sync* are added together. *P* and *Sync* are also adding stages. The signal corresponding to the horizontal bars is fed from an oscillator *HB*, and that for the vertical bars from an oscillator *VB* to the stage *P*. Both line and frame synchronisation pulses are supplied to the adding stage *Sync*. The former are produced by a unit *LS* controlled by the freely running oscillator *LO*. An oscillator *RS* produces the frame synchronization signals and is synchronized by an oscillator *RB* which produces the frame blanking signals. This in turn is controlled by pulses of mains frequency which are derived from the mains voltage via a network *N*. An oscillator *LB* supplies the line blanking signal and is synchronized by *LS*.

Using switches S_1 and S_2 a choice can be made between horizontal bars, vertical bars, or both at the same time. For testing the audio channel, S_1 is put in the top position (fig. 10); the horizontal-bar generator, on the models with frequency modulation, then feeds a reactance valve (*Re*) which modulates the oscillator *Osc* in frequency. At the same time, with S_1 in the top position, S_3 and S_4 are closed: S_3 short circuits the input of the modulator so that no video signal can occur on it (the modulator then simply operates as an amplifier), and S_4 prevents blanking signals from *RB* occurring in the audio signal supplied by *HB*; these signals, due to their frequency (50 c/s), would make the sound less pleasant to the ear.

Some of the networks mentioned will now be dealt with more fully.

Relaxation oscillators

Several of the networks dealt with are relaxation oscillators which generate a square wave signal. These are the networks *RB*, *HB*, *RS*, *LB* and *VB*.

In *HB*, the generator of the horizontal bars, a triode-pentode ECL 80 is used, operating as a multi-vibrator. The frequency can be varied from about 300 to 500 c/s, corresponding to about 6 to 10 horizontal bars.

The generator of the blanking signal, *RB*, likewise operates with a valve ECL 80 in a similar type of circuit, but the two halves of the tube are asymmetrically connected so as to give a monostable flip-flop. The leak resistor of the triode grid is held at a high positive voltage, whilst the pentode control grid has a negative grid bias (the voltage drop across a cathode resistor); consequently, the circuit is stable only when the triode is conducting. If now a negative pulse is applied to the triode grid, the triode will be temporarily cut-off, and the pentode will be conducting. A quasi-stable condition now exists, which will last for a certain period (dependent on the particular resistance and capacitance values), after which the original condition is restored. In the quasi-stable state, the anode potential of the pentode drops, because of the voltage drop in its anode resistor. Hence the screen grid of the multi-vibrator *HB* also drops in potential, since it is directly connected to this anode. The screen grid potential drops below the cathode potential of *HB* so that this multi-vibrator does not work while *RB* is in the quasi-stable condition.

As already stated, this latter condition is initiated each time by a negative pulse on the triode grid of *RB*. The network *N* shapes these pulses from the mains voltage, in the

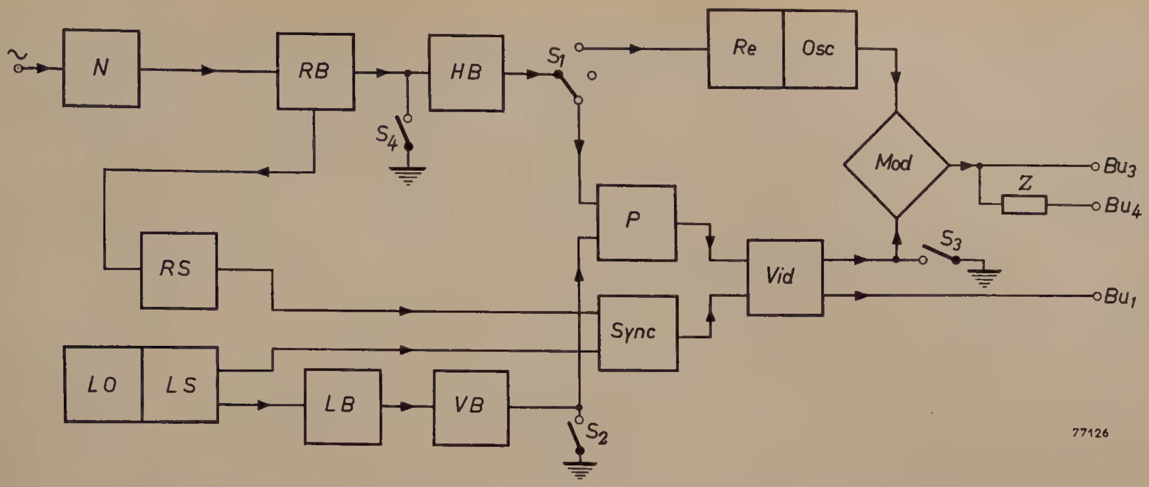

Fig. 10. Block diagram of the generator 2887. *N* generator of pulses of mains frequency. *RB* generator of frame blanking signal. *RS* generator of frame synchronization signal. *HB* generator of horizontal bars. *LO* freely running line oscillator. *LS* generator of line synchronization signal. *LB* generator of line blanking signal. *VB* generator of vertical bars. *P* adding stage for horizontal and vertical bars. *Sync* adding stage of the signals for horizontal and vertical synchronization. *Vid* adding stage for picture and synchronization signals. *Re* reactance modulator (in the models with frequency modulation only). *Osc* high frequency oscillator. *Mod* modulator. Bu_1 output terminal for the video signal. Bu_3 output for modulated high frequency voltage. Bu_4 same output, attenuated by a factor of approximately 1/50 by the attenuater *Z*. S_1, S_3, S_2 and S_4 switches.

following manner. A transformer connected to the mains has its secondary in series with a resistor and a neon tube (type Z1M). The voltage waveform across this tube is represented by the full line in *fig. 11a*. Each time the tube fires, a sudden voltage drop occurs from the ignition voltage to the running voltage. With the aid of a differentiating circuit, a pulse (fig. 11*b*) is obtained at each voltage drop, so that one positive and one negative pulse occur per cycle of the mains voltage. Each negative pulse brings the multivibrator *RB* from the stable to the quasi-stable state, and this stops the multivibrator *HB*.

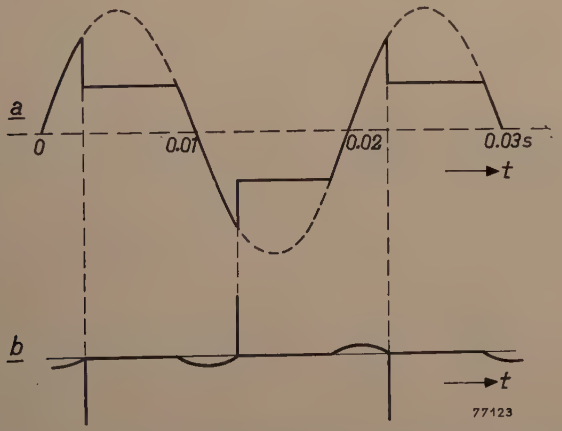

Fig. 11. *a*) Dashed curve: sinusoidal voltage having mains frequency. Full line: voltage across the neon tube in network *N*. From this latter voltage, by differentiation, a steep-shaped pulse (*b*) is produced.

The generator *RS* of the frame synchronization signal is, in the main, arranged similarly to *RB* and is controlled by *RB* — thus ultimately by the mains frequency. *RB* and *RS* thus go over simultaneously into the quasi-stable state, but with *RB* this lasts longer than with *RS*; the difference between them is the duration of the back porch.

The generators *LS*, *LB* and *VB* generate the line synchronization signal, the line blanking signal and the vertical bars signal respectively, and are analogous to *RS*, *RB* and *HB*. Of course, the frequency is much higher: *LS* and *LB* operate with the line frequency f_l, which, according to the system, is approximately 10, 15 or 20 kilocycles; *VB* operates with a frequency which is variable from $6f_l$ to $10f_l$.

Line oscillator and line synchroniser

The line frequency f_l is determined by an *L-C* oscillator *LO*, oscillating at its natural frequency. A fixed capacitance is used and the inductance is permanently adjusted, by means of a sliding core of Ferroxcube, so that f_l approaches the required value as closely as possible.

The pulses which synchronise *LS* and *LB* have to be derived from the sinusoidal voltage of this oscillator. This is done in the following manner.

Across the *L-C* circuit of *LO* there is a sinusoidal voltage approximately 200 volts in amplitude. A part of this (v_2) is fed, via a capacitor and a leak resistor, to the triode grid of the valve ECL 80, the pentode of which acts as the oscillating valve in *LO*. Since the amplitude of the alternating voltage v_2 exceeds the cut-off voltage by many times, there is a high negative grid bias, (*fig. 12a*) so that the triode passes current only at the positive peaks of the alternating voltage (fig. 12*b*). These anode current pulses drive a second *LC* circuit; the voltage v_3 developed across this circuit is shown in fig. 12*c*. This voltage is used for generating the line synchronization pulses, in such a way that these pulses continue during the frame synchronization, so that the saw-tooth generator of the receiver has no chance of getting out of step. It would be going too far to deal with the details of this circuit here.

Adding stages

There are three adding stages in the GM 2887 signal-generator: *P*, *Sync* and *Vid* (fig. 10); in *P* the picture signal is formed, and in *Sync* the synchronization signal, whilst in *Vid* these two are combined to form the video signal. The "adding" of the two signals v' and v'' is actually here the shaping of a

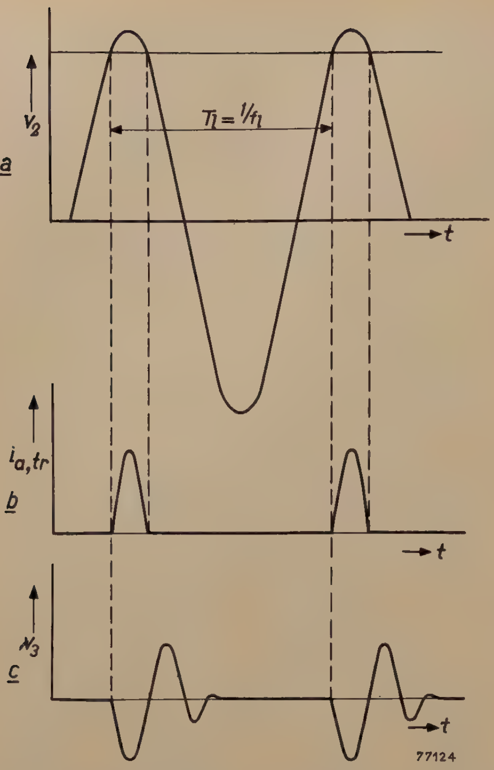

Fig. 12. *a*) Sinusoidal voltage v_2 across a part of the *LC* circuit of the line oscillator *LO*. Only the peaks of v_2 are above the cut-off voltage of the triode of *LS*. *b*) Pulse-shaped anode current of the triode of *LS*. *c*) The damped alternating voltage v_3 across the *LC* circuit of *LS*.

linear combination of them, say $av' + bv''$. As shown in *fig. 13* this can be effected with the aid of two valves having a common anode resistance. The adding stages in question function according to this principle; in each of the adding stages two valves as shown in fig. 13 are combined into one double tube, again of the type ECL 80.

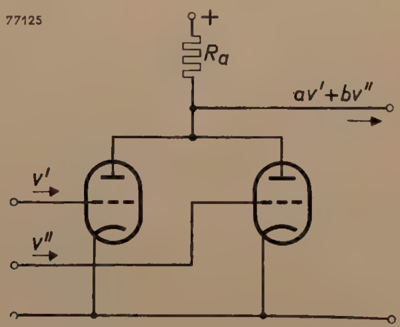

Fig. 13. Principle of an adding stage: two amplifying valves with a common anode resistance R_a. A signal $av' + bv''$, which is a linear combination of the signals v' and v'' on each of the grids, is produced at the anodes.

Oscillator, modulator and reactance modulator

The networks drawn in fig. 10 are almost identical for the four models (A, B, C and D), except for the line frequency and the frequency range of *VB*. There remain, however, three more networks: the high frequency oscillator *Osc*, the modulator *Mod* and (in the models with frequency modulation) the reactance modulator *Re*. Together these form a unit. The models with frequency modulation (A and C) will mainly be dealt with here.

One half (*II*) of a double triode ECC 81, (*fig. 14*), together with a resonant circuit L_1C_1 forms the high frequency oscillator. The other half of the tube (*I*) in the models with frequency modulation (A and C) serves as a reactance valve, i.e. it behaves as a reactance connected in parallel to the circuit L_1C_1, of magnitude dependent upon the slope of the valve. This slope varies with the audio frequency signal, so that the oscillator voltage is modulated in frequency. As already remarked, the signal of the horizontal bars, produced by the generator *HB*, functions as an audio-frequency signal.

The oscillator voltage is fed to one half (*III*) of a second double triode ECC 81. This half is arranged as a cathode follower. The cathode is thus the output electrode; it is connected with the cathode of the other half (*IV*) of this tube, which functions as a modulator. The video signal derived from the adding stage *Vid*, is applied to the grid of *IV* which for high frequency voltages is earthed across a capacitor. The output is taken off at the anode of *IV*, and in models *A*, *B* and *C*, passes via two coupled coils (L_2-L_3), so as to give a signal symmetrical with respect to earth. It is available in this form at the socket Bu_3 and, attenuated by a factor of 1/50 by a potentiometer (*Z*), at socket Bu_4.

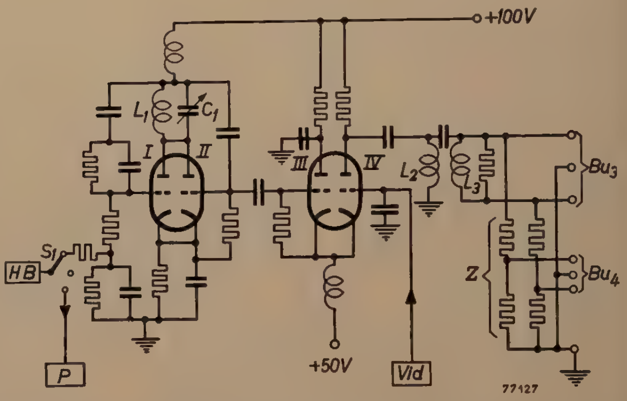

Fig. 14. Circuit of the reactance modulator, the high frequency oscillator and the modulator. Of two double triodes ECC 81, *I* serves as a reactance valve, *II* (together with the vibrator circuit L_1C_1) as oscillator, *III* as amplifier, arranged as cathode follower, and *IV* as modulator. For high frequencies the grid of *IV* is earthed across a capacitor. To this grid is applied the video signal from the adding stage *Vid* which combines the picture signal and the synchronization signal. A symmetrical output voltage is obtained at the socket Bu_3 by means of the coupled coils L_2 and L_3. This voltage is attenuated at the socket Bu_4 to about 1/50, by a potentiometer composed of resistors (*Z*). The audio-frequency signal is fed to the reactance valve via the switch S_1.

The video-signal is supplied to the modulator with such a polarity that the modulation has the required sign (the International and the American standards specify negative modulation, while the British and the French standards specify positive modulation).

The versions of the generator GM 2887 for these latter two systems — models B and D — differ from the diagram in fig. 14 in so far as the second channel uses amplitude modulation instead of F.M.

Summary. The signal generator GM 2887 described supplies signals with which various types of faults in TV receivers may be traced, independent of the operation of the local TV transmitters. The apparatus is also useful for adjustment of

the picture. In the design, the aim has been to make the generator easily portable (weight 7 kg, dimensions 335 × 220 × 165 mm, or $15^1/_2$ lb. and 13″ × $8^1/_2$″ × $6^1/_2$″). The number of valves has been restricted to 13 (9 triode-pentodes ECL 80, 2 double triodes ECC 81, 1 rectifying tube AZ 41 and 1 neon tube Z1M) — thanks to the use of double tubes, and the omission of frequency dividers for the derivation of frame frequency from line frequency. The mains frequency is used as the frame frequency, and the line frequency is generated by a freely running LC oscillator. As a consequence, the pattern lines do not remain absolutely stationary, but this is not a serious objection in view of the simplicity of the patterns supplied by the generator (horizontal and/or vertical bars). Due to the fact that in the various countries different TV standards are in use, the generator is manufactured in four models:

Models A and C with negative picture modulation, 625 lines or 525 lines, and frequency-modulated audio-channel. Model A is for the low frequency band and C for the high frequency band of the countries with either the "International" or the American standard; B and D with positive picture modulation and amplitude-modulated audio channel. Model B is for 405 lines (British standard), Model D for 819 lines (French standard).

BOOK REVIEW

Data and circuits of radio receiver and amplifier valves (Second supplement: Valves developed between 1945 and 1950), by N. S. Markus and J. Otte, pp. 487, 505 illustrations. — Philips Technical Library, 1952 (Volume IIIa of the Electronic Tube Series) — This book may be ordered through your technical bookseller.

This volume, together with volumes II (1933-1939) and III (1940-1941), forms a compendium of the electronic valves (and some measuring instruments) developed by Philips during the years 1945-1950. Volume III, which precedes this one, has not been reviewed in this journal, as it was published shortly before the Philips Technical Review had to cease publication in 1942. The present volume deals chiefly with the small tubes produced since the war for broadcast receivers - the so-called "Rimlock" valves (E, U and D series). In addition, the book deals with four miniature D series valves for battery operation, and three "Noval" tubes which have a nine-pin base. The book also contains descriptions of 15 new measuring equipments manufactured by Philips, which supplement those given in Volumes II and III.

The great improvements in the mechanical construction of receivers which has resulted from the development of these small tubes is at once evident from a comparison of the interior of a set equipped with these tubes with an earlier set embodying similar circuits. In the introduction to this book, it is explained how the dimensions of these valves were reduced without impairing their characteristics, reliability or cost.

In all, 36 types of valve are described, together with a number of detailed circuits of complete receivers and amplifiers in which they are used. An outstanding feature of the book is the comprehensive way in which each type of tube is discussed. The reader is thus able to find everything he wants to know about a certain valve. This method of treating the subject has made the book large but it enhances its value: the more so because the text also gives the agreeable impression that it has been compiled with great care.

The scope of this review does not permit a separate enumeration of all the Philips measuring instruments described: they include two cathode-ray oscilloscopes, high and low frequency oscillators and electronic voltmeters. The most impressive apparatus is the large oscilloscope GM 5653, whose amplifier has a frequency range of 5 Mc/s, which makes it admirably suitable for television servicing. Also described is a standard oscillator, type GM 2885, driven by a crystal-controlled 1 Mc/s oscillator, from which a large number of precise derived frequencies can be obtained by frequency multiplication and by mixing with an auxiliary oscillator (0.5-1.0 Mc/s). A third apparatus worthy of mention is the variable low frequency *RC*-generator, GM 2315.

A few of the valves described are special types whose field of application lies outside that of normal broadcast reception. The most important of these are the "φ-detector" or enneode [1]) EQ 80 (for F.M.), the multi-purpose pentode EF 42 (for wide frequency band amplification) and the ubiquitous double triode ECC 40 (for push-pull circuits, television apparatus, pulse generators, electronic computors, etc.). The discussion of this last type of tube and its applications, though occupying 16 pages, could, in the writer's opinion, have been more elaborate; some literature references for this type of tube and also for the EQ 80 are desirable. This criticism, however, should in no way mitigate the favourable general impression of this very practical book.

J. van SLOOTEN.

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[1]) See also J. L. H. Jonker and A. J. W. M. van Overbeek, Philips tech. Rev. **11**, 1-11, 1949.

THE FOCUSING OF TELEVISION PICTURE-TUBES WITH FERROXDURE MAGNETS

by J. A. VERHOEF.

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*In 1950-51 Philips developed Ferroxdure *), a ceramic permanent-magnet material. One of the most important applications of this material, which takes full advantage of its special properties, is in focusing magnets for television picture-tubes.*

Magnetic electron lenses

For the focusing of the electron beam in television picture-tubes, magnetic lenses are commonly used. The focusing action results from the magnetic field which has rotational symmetry about the axis of the lens. The focal length f is given by

$$\frac{1}{f} = \frac{0.0347}{V} \int_{z=-\infty}^{z=+\infty} H_z^2 \, \mathrm{d}z \,, \quad . \; . \; . \; (1)$$

where V is the potential difference traversed by the electrons before they enter the lens and H_z is the field strength on the axis of the lens [1]).

If an electromagnetic lens is used, both V and H_z vary somewhat with the supply voltage. The circuit can be designed such that these variations largely compensate each other. This is of course no longer possible when permanent magnets are used because only V then varies with the supply voltage. Nevertheless, permanent magnet lenses are usually preferred nowadays to the electromagnetic type of lens. There is no need to supply the considerable power which is required to energize an electromagnetic lens, so that the power pack can be simpler. At the same time one source of heat in the apparatus is eliminated. Finally, the cost of manufacture of permanent magnet lenses is considerably less than that of electromagnetic lenses.

In spite of the above-mentioned advantages, the conventional permanent magnet lens has the serious disadvantage that the field is spread out along the axis much further than that of an electromagnetic lens of the same strength. The reasons why such an extended field is undesirable will first be discussed. The fundamental difference between electromagnetic and permanent magnet lenses will then be considered more closely. Finally it will be shown how the stray field of permanent magnet lenses can be considerably restricted. It will become evident that, for this purpose, a magnetic material of high coercivity is necessary. Some of the "Ticonal" magnet steels satisfy this requirement. However, an important economic advantage is gained by the use of Ferroxdure, the new permanent-magnet ceramic, one of whose distinctive properties is a high coercivity [2]). In addition to the low cost of Ferroxdure, its use leads to a very simple construction.

Some consequences of a strong stray field

The electron lens is situated on the neck of the tube between the ion trap and the deflection coils (*fig. 1*). Especially when a short-neck tube is used [3]), these three components are so close together that the field from a conventional permanent magnet lens still has a considerable value at the ion trap and the deflection coils (*fig. 2*). The result is that if the position or strength of the lens is changed, the angle through which the ion trap deflects the electron beam is also changed. The beam then goes eccentrically through the tube, so that the raster, which is "written" by the electron beam on the screen of the tube is no longer well-centered. Furthermore, part of the beam will now be cut off by the diaphragm (*fig. 3*), so that the brightness

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*) Also known by the name "Magnadur".

[1]) With the constant used, the formula is expressed in rationalized Georgi units. V is expressed in volts, z and f in metres and H_z in A/m (1 A/m = 1.251×10^{-2} oersted). The validity of eq. 1 is limited to the case of a "thin" lens, i.e. a lens in which the axial extent of the field is small compared with the object and image distances. If the lens is not thin, other terms must be added to the expression (1). As H_z appears, in these terms too, only in even powers, the focal length is always independent of the sign of H_z, the importance of which will be seen presently.

[2]) J. J. Went, G. W. Rathenau, E. W. Gorter and G. W. van Oosterhout, Ferroxdure, a class of new permanent magnet materials. Philips tech. Rev. **13**, 194-208, 1952.

[3]) The reasons why the neck of a picture tube should be kept short, and means by which this may be achieved were discussed recently in this Review. See J. L. H. Jonker, A short length direct-view picture-tube, Philips tech. Rev. **14**, 361-367, 1953 (No. 12).

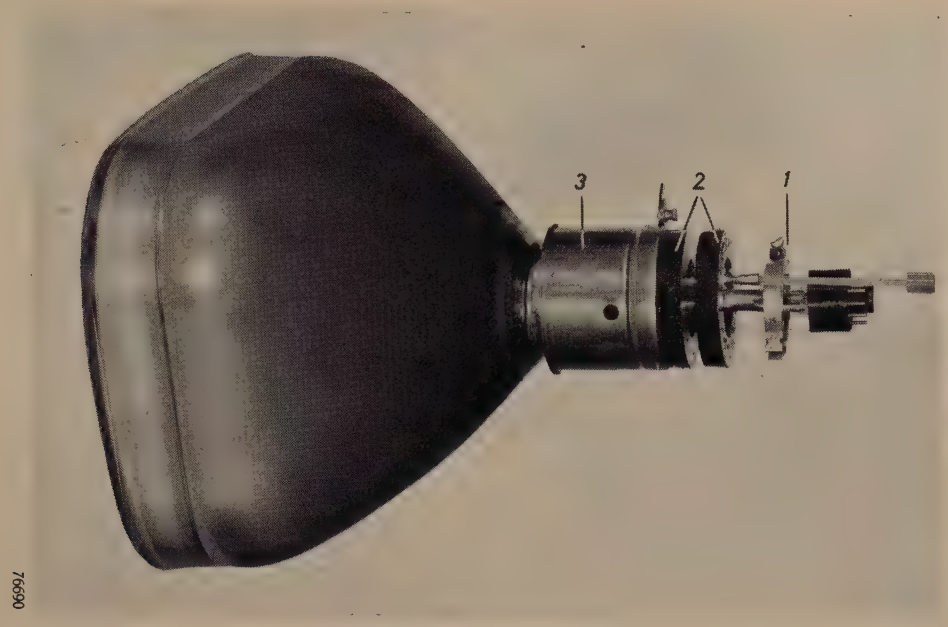

Fig. 1. Television picture-tube (diagonal = 36 cm). Mounted on the neck are: *1* ion trap magnet, *2* electron lenses, *3* deflection coils.

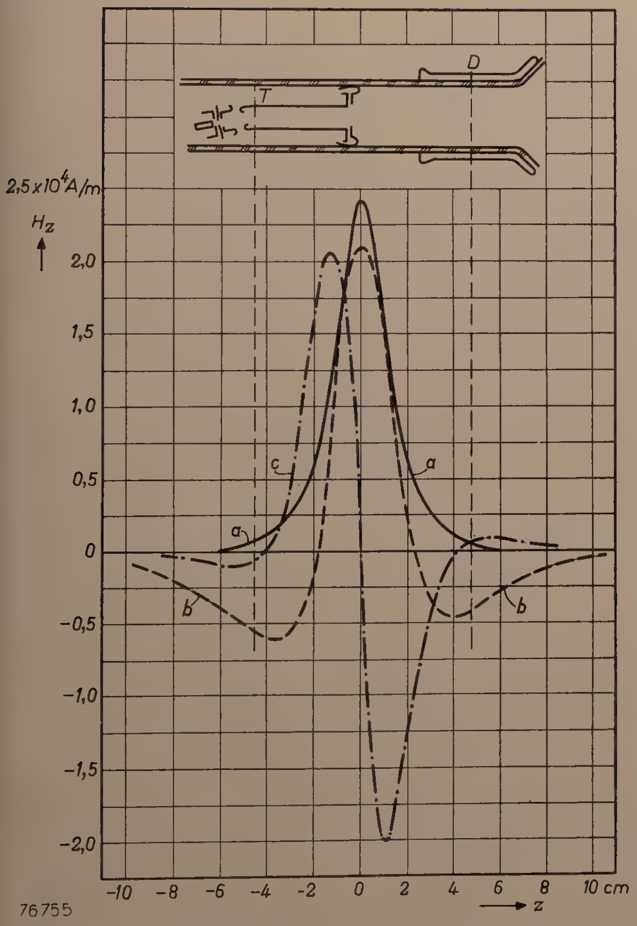

Fig. 2. The form of the field along the axis of a picture-tube, due to *a*) an electromagnetic lens, *b*) a conventional permanent magnet lens, and *c*) a permanent magnet lens of the new type. The conventional permanent magnet lens (*b*) gives rise to a field with a considerable "tail", which is still quite strong at the ion trap *T* and at the deflection coils *D*.

diminishes. If the field of the focusing magnet extends to the deflection coils, a rotation is caused as well as a distortion of the picture, which changes when the lens is adjusted. By a renewed adjustment of the ion trap magnet and of the deflection coils, these distortions can be corrected again, but the mutual interaction between the electron lens and the ion trap magnet and the deflection coils is very undesirable; apart from the inconvenience of the successive adjustments, the adjustment for the optimum light spot on the screen is upset.

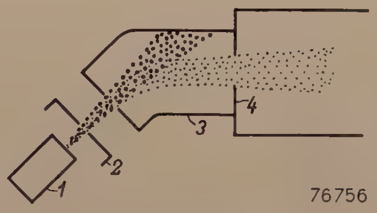

Fig. 3. Schematic representation of an ion trap. The electron beam emitted by the cathode *1* always contains negative ions which would damage the screen of the tube. A local magnetic field, perpendicular to the plane of the drawing, bends the electron beam so that it passes through the aperture in the diaphragm *4*. The ions (large dots) are negligibly affected and thus fall on the anode *3*. *2* is the control grid.

Electromagnetic and permanent-magnet electron lenses

An electromagnetic lens consists of a coil enclosed in a soft iron casing provided with an internal air gap (*fig. 4a*). The strength of the lens depends on the current through the coil. A permanent magnet lens of conventional construction consists of an axially magnetized ring of "Ticonal" or a similar magnet steel, provided with pole pieces (*fig. 5a*).

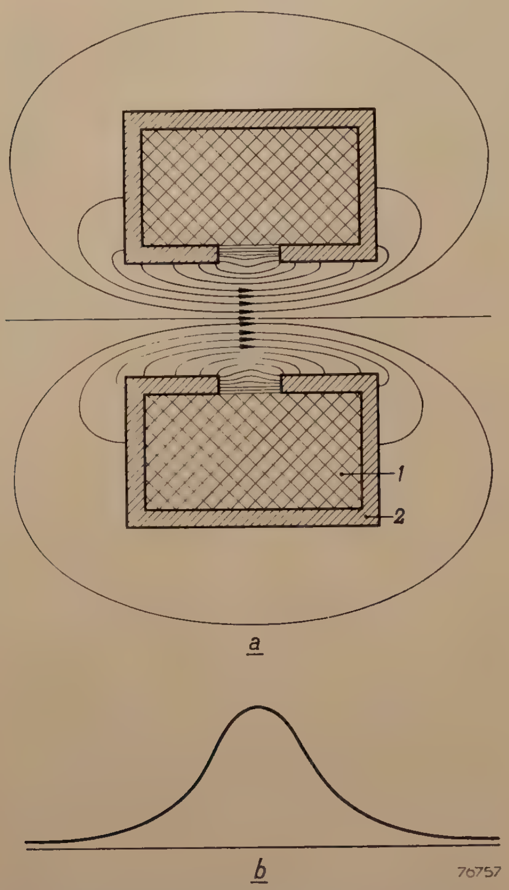

Fig. 4. *a*) Schematic representation of the construction of an electromagnetic electron lens showing the lines of force. The coil *1* is surrounded by a soft iron casing *2*, which has an air gap. The strength of the lens is controlled by varying the current through the coil.
b) The form of the field along the axis of the lens shown in (*a*).

The strength of such a lens can be varied by means of an adjustable soft iron ring. The more this ring bridges the gap between the pole pieces (the more the air gap is short-circuited), the weaker the lens. In figs. 4*b* and 5*b* are plotted the field strengths along the axis for the two types of lens. The essential difference is that with an electromagnetic lens the field strength is nowhere negative, while that of the permanent magnetic lens necessarily has both positive and negative values. Considering the area between the curve and the z-axis as positive above the axis and negative below it, the total area for a permanent magnet lens amounts to zero, whilst for an electromagnetic lens it is proportional to $n{\cdot}i$ (n is the number of turns of the coil and i is the current). This area is, in fact, a measure of the line integral of the field through the lens along the axis. From Maxwell's theory, in the case of permanent magnets,

$$\int_{z=-\infty}^{z=+\infty} H_z \mathrm{d}z = 0,$$

since no electric currents are flowing. For an electromagnetic lens on the other hand we have

$$\int_{z=-\infty}^{z=+\infty} H_z \,\mathrm{d}z = n{\cdot}i\,.$$

The strength of a lens is determined by the form of H_z^2 (see Eq. (1) and footnote [1])), so that, as far as its focusing action is concerned, it is of no consequence that the line integral of the field of the permanent magnet is zero. With a Ferroxdure lens the importance of this fact is even more striking than with a conventional lens, as will be seen presently.

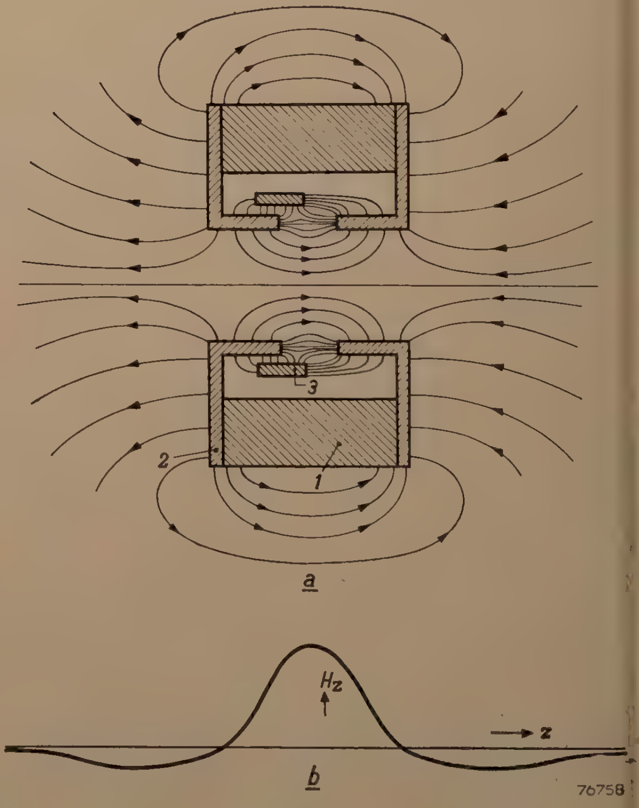

Fig. 5. *a*) Schematic representation of the construction of a permanent magnet lens showing the lines of force. *1* annular piece of magnet steel, *2* pole pieces, *3* moveable soft-iron ring by means of which the strength of the lens may be varied.
b) Form of the field along the axis of this lens. The algebraic sum of the areas under the curve above and below the *z*-axis is here zero.

A better physical picture of the essential difference between an electromagnetic lens and a permanent magnet lens may be obtained as follows. First consider first the field of a cylindrical film of current (of length L and diameter D), e.g. that which results from passing a current through a coil of one layer of thin wire(of diameter small compared to D). This field can be calculated by elementary methods. In *fig. 6* the field along the axis is plotted for different values of the ratio D/L. It can be seen that for constant length L, the field is more concentrated when the current film diameter D is smaller. Neglecting the influence of the soft-iron casing of the electromagnetic lens, the field of the whole coil can be obtained by the superposition of the fields of the separate current films with different values of D/L. The resulting field will be roughly bell-shaped, as in the curves of fig. 6. For a permanent magnet lens the situation is different. Neglecting the influence of the pole pieces, the lens has the form of a ring-shaped magnet. It is assumed that the ring is uniformly magnetized in an axial direction and that the magnetization is due to circular atomic currents which lie in a plane perpendicular to the axis of the magnet (*fig. 7*). The electric charges, except those which move at the inner and outer surfaces of the ring, neutralize each other's influence outside the magnet itself. The net effect of the whole magnetization, as far as the space outside the magnet is concerned, is the same as the effect of two current films of equal strength per unit length flowing in opposite directions along the inner and outer surfaces. The superposition of the fields of these current gives the field of the magnetized ring (*fig. 8*).

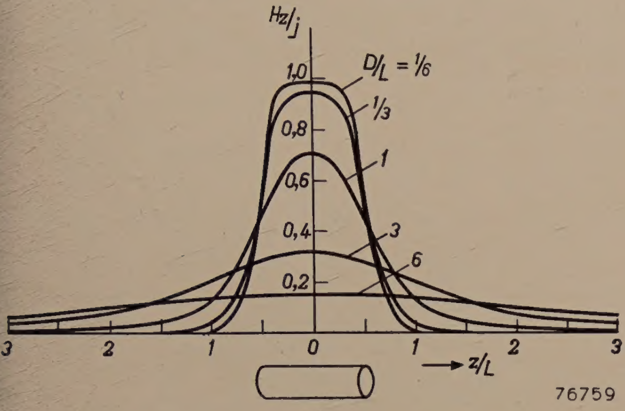

Fig. 6. Calculated distribution of the axial field of cylindrical current films of length L and diameter D. The position of the current film is shown by the sketch just under the graphs. The greater the parameter D/L, the more the field is spread out along the axis. Along the abscissa is plotted H_z/j, where j is the current per unit length of the current film. If j is expressed in A/m, then H is also given in A/m (in rationalized Giorgi units, 1 A/m ≈ 1/80 oersted).

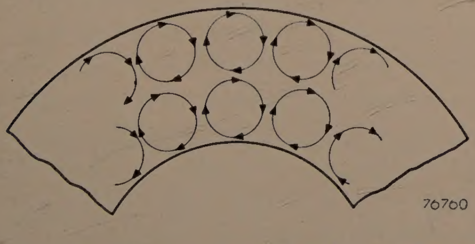

Fig. 7. The magnetization of a uniformly, axially magnetized ring can be thought of as originating in circular atomic currents in the plane perpendicular to the axis of the ring. The field outside the magnetized material is then equivalent to that of two current films flowing in opposite directions along the inner and outer surfaces of the ring.

Some idea of the effect of a soft iron casing placed round the current coil, in the case of the electromagnetic lens, can be obtained by regarding the total field as due to the superposition of the original field of the coil and the field of the casing, which becomes magnetized by the field of the coil. Due to the casing the field becomes more concentrated and less spread out along the axis (see the lines of force in fig. 4*a*). If the casing is made without an air gap, a field would still exist outside the casing ($\oint H_l \, dl = n \cdot i$ remains valid!)

The form of the field of a permanent magnet lens with pole pieces can be visualized by considering the lens as a magnetic circuit with two parallel air gaps — a narrow gap on the inside and a wide gap on the outside. The field in the latter gap is responsible for the negative parts of the field on the axis (fig. 5.) The negative part of the field cannot be avoided, because the value of the line integral along the axis must always be zero. Should one try to avoid the negative field, for example by making the outer air gap smaller with the aid of pole pieces, then at the same time the useful field of the inner air gap would be weakened. Closing one of the air gaps would have the result that the field on the axis would disappear completely. The task of the pole pieces in the conventional permanent magnet lens is principally to enable the lens strength to be varied by means of the moveable ring (fig. 5*a*), and the smoothing out of rotational asymmetries of the magnetization of the magnet ring.

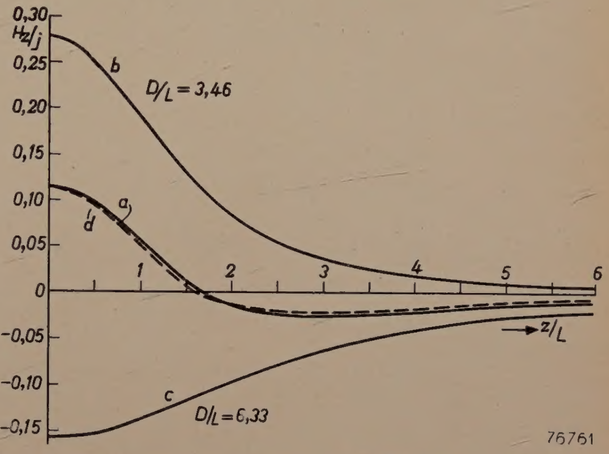

Fig. 8. Theoretical distribution of the field along the axis of a homogeneously magnetized ring (curve *a*), obtained by superposing the fields due to the current films on the inner (curve *b*) and outer surfaces (curve *c*), where D/L is 3.46 and 6.33 respectively. (These values apply to the Ferroxdure rings used for focusing in television picture-tubes.) Curve *d* is the measured field of such a ring. The maxima of the theoretical and the measured curves have been made coincident. The slight deviation between the two curves is attributable to inhomogeneous magnetization in the axial and radial directions. The curves are symmetrical on either side of the vertical axis.

Focusing with Ferroxdure magnets

To reduce the stray field, a lens hasb een developed which consists of two flat rings of Ferroxdure, coaxially mounted and axially magnetized in opposite directions (*fig. 9*). Apart from the central region, the fields now largely neutralize each other (*fig. 10*). The total area under the curve $H_z = f(z)$, of course, remains zero, for this is the case for any combination of permanent magnets. As has already been pointed out, this is not in any way opposed to the satisfactory operation of this lens, because the strength of the lens is determined exclusively by the form of H_z^2 (dotted line, fig. 10*b*).

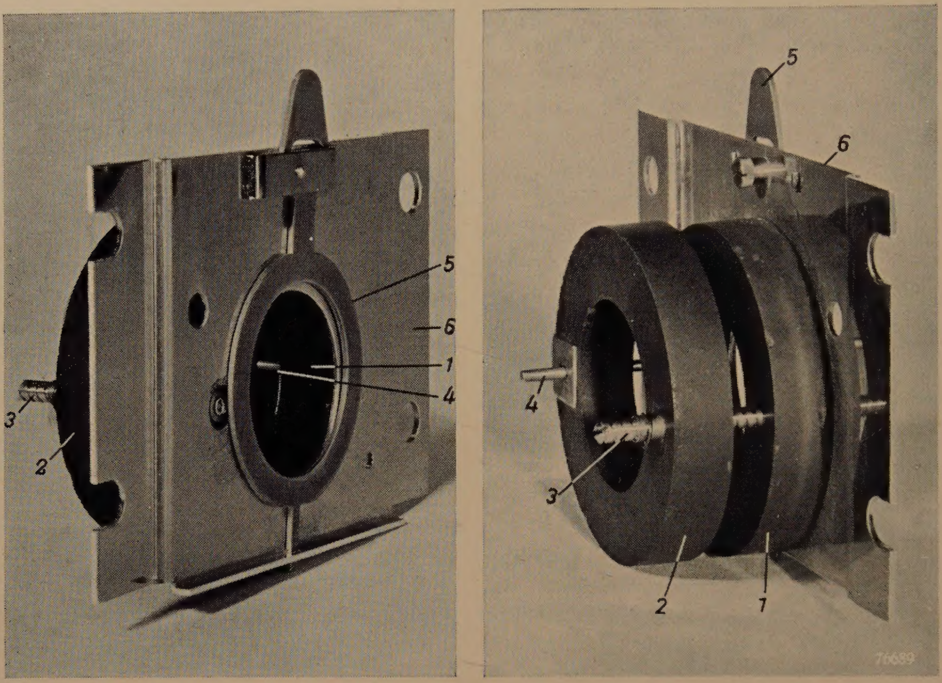

Fig. 9. Two photographs of a focusing unit made up of two Ferroxdure rings (*1* and *2*) axially magnetized in opposite directions. The distance between the rings is adjusted by the screw *3*. *4* is a guide pin, *5* an adjustable soft iron ring with which the electron beam can be centered. The plate *6* is of aluminium. The focusing unit seen in fig. 1 is of slightly different construction.

As the value of $(BH)_{\max}$ is much smaller for Ferroxdure than for the magnet steels commonly used in conventional permanent magnet lenses, e.g. "Ticonal" E, it is not surprising that a greater total volume of Ferroxdure is needed than of Ticonal "E", to produce a lens of a given strength [4]). In spite of this fact and in spite of the division of the material into two separate rings, the whole lens is no longer than the conventional lens, thanks to the flat form of the rings. This flat shape is possible owing to the great coercitivity of Ferroxdure. (The field strength which would be necessary to reduce the magnetization to zero is about 2.4×10^5 A/m (3000 oersted), while that of Ticonal E amounts to only 0.53×10^5 A/m (660 oersted).) Compared with Ticonal E, Ferroxdure is therefore much less demagnetized by the field of the magnetic poles which establish themselves at the end faces of the ring. With a given volume of magnetic material and a given internal radius, if the axial length L is made smaller (and so the radial dimension h greater, *fig. 11*) then the poles which produce the demagnetization field come closer together and the strength of this increases. In the case of Ticonal E, this field would soon reduce the magnetization to only a fraction of the remanence: if two flat, oppositely magnetized rings of Ticonal E were assembled to form a lens, they would destroy each others magnetization almost completely. Evidently this material cannot be applied in the case of flat rings. With Ferroxdure, on the other hand, however thin the ring is made, the magnetization (*fig. 12*) never falls below 80% of the remanence [5]). In the extreme case, when the thickness

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[4]) A. Th. van Urk, The use of modern steels for permanent magnets, Philips tech. Rev. 5, 29-35, 1940. Some further remarks concerning the product $(BH)_{\max}$, may be found in the article referred to in note [2]), on p. 116 and p. 202.

[5]) Lenses consisting of two oppositely magnetized rings can be constructed of "Ticonal", provided that Ticonal K is used; for completeness its demagnetization curve is also given in fig. 12. The application of Ferroxdure, however, leads to a more economic solution.

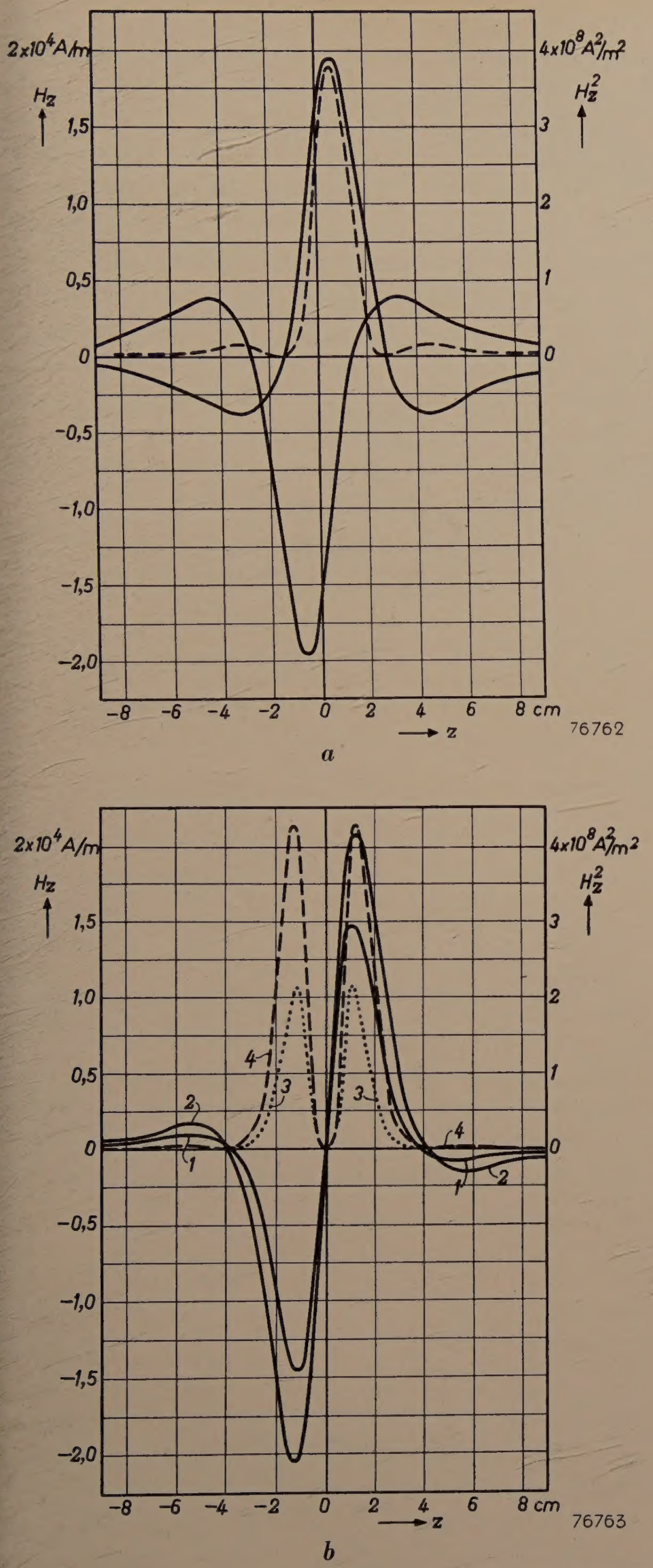

Fig. 10. *a*) The separate axial fields of two oppositely directed Ferroxdure rings are depicted here in the one figure. The curves are displaced with respect to each other by a distance corresponding to the thickness of one ring. For one of the rings (the right-hand one) the form of H_z^2 is drawn in dotted lines.
b) Curve *1* shows the resultant field along the axis of a lens with the two rings placed face to face; curve *2* shows the field when the rings are separated by 10 mm. The dotted curves *3* and *4* show the form of H_z^2 along the axis for these two cases.

of the ring is made equal to zero, the working point (i.e. the point on the demagnetization curve corresponding to the magnetic condition of the material) is found to be the intersection of the line $J = -\mu_0 H$ with the demagnetization curve (μ_0 is the permeability of free space). The disastrous result for Ticonal E can be seen in fig. 12, where the magnetization drops from a very high value for a long magnet, to the point P_1 for a magnet of zero length; on the other hand the change in the magnetization of Ferroxdure ($R - P_2$) is very small indeed.

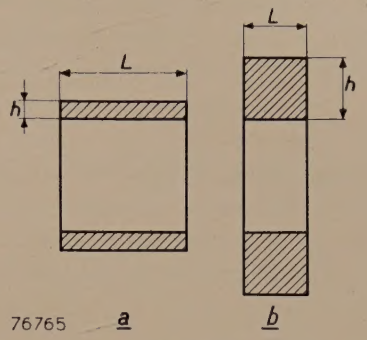

Fig. 11. Cross-sections of ring-shaped magnets for television tube focusing.
a) For a lens of the conventional type using magnet steel.
b) For a lens of the new type, using Ferroxdure.

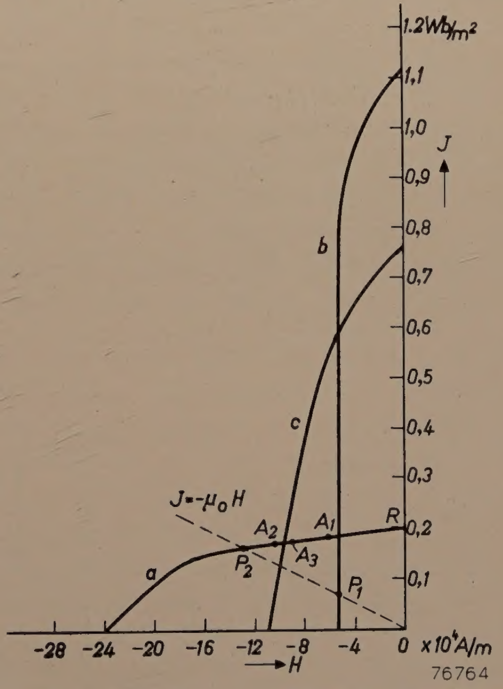

Fig. 12. Demagnetization curves of Ferroxdure (curve *a*), "Ticonal" E (curve *b*) and "Ticonal" K (curve *c*). Note that the magnetization J is plotted along the vertical axis, and not the magnetic induction. The point R represents the remanent magnetization of Ferroxdure. With a focussing unit as in fig. 9 the working point of the Ferroxdure lies between A_2 and A_3, depending on the distance between the two rings. A_1 is the working point for a single ring not influenced by the field of another magnet. P_1 and P_2 are the working points for very thin flat discs of Ticonal E and Ferroxdure respectively.

Even with Ferroxdure, however, the rings cannot be made thinner indefinitely. The opposite poles on the two end faces will neutralize each other's external fields more and more as the rings are made thinner. Accordingly, the field along the axis decreases quickly as L becomes considerably smaller than h. For the actual rings used, $L \approx h$.

The ceramic Ferroxdure rings can more easily be made homogeneous than rings made from magnet steel. Hence the magnetization shows the same rotational symmetry as the ring and no soft iron pole pieces are necessary to ensure a field with rotational symmetry.

The strength of the Ferroxdure lens is varied by adjusting the distance between the two rings (fig. 9). As the distance is increased, there is less mutual neutralization of the main fields, and thus the lens becomes stronger. The neutralizing of the stray field is then less complete, but it is still adequate, even over the whole range of adjustment of the lens strength, which is at least as great as that of a conventional permanent magnet lens, and often greater. ("Adequate" neutralization implies that the operation of the ion trap magnet and of the deflection coils are only slightly influenced by the electron lens. The adjustment of these components can then be made independently). In a given case, it proves possible to obtain good focusing of the electron beam for any acceleration potential between 10 and 20 kV (see Eq (1)), by varying the separation of the two rings between 0 and 12 mm.

The two rings, magnetized in opposite directions and situated in each other's field, exercise on each other a demagnetizing field. If the separation of the rings is such that they exert no demagnetizing field on each other, the working point lies approximately at the point A_1 (fig. 12). As the rings are brought closer together, the working point moves towards A_2. With the normal spacing of the rings, the working point lies between A_2 and A_3. The position of the working point is important because, with Ferroxdure, the magnetization depends on the temperature, and the temperature coefficient varies with the position of the working point. Near the point R the temperature coefficient is about -0.2% per °C, but in the region between A_2 and A_3 it is only about half this value. With some thought, television sets can be so designed that the rise of temperature of the magnet rings remains so small that the influence on the picture definition is imperceptible.

In practice the picture is never accurately centered on the screen of the tube without some adjustment. In the Ferroxdure lens, a thin soft iron ring is placed against the first magnet (fig. 9). By moving this soft iron ring, a movement of the picture across the screen can be achieved.

Summary. By the application of the distinctive properties of Ferroxdure, the new ceramic material for permanent magnets, it is possible to construct a simplified permanent magnet lens for the focusing of the electron beam in television picture-tubes. The lens is characterized by a stray field along the axis which is considerably less than that of permanent magnet lenses of the conventional type. The lens consists of two axially magnetized rings of Ferroxdure which are mounted together, like poles facing each other. The stray fields of the two rings then largely neutralize each other. The strength of the lens is adjusted by varying the mutual separation of the rings. Centering the picture on the screen is accomplished simply by moving a soft iron centering ring.

Adjustment of the lens strength does not affect the adjustment of the ion trap magnet, and causes only a negligible rotation of the picture. The adjustment of the ion trap magnet, the lens itself and the deflection coils is thereby simplified. As a result of the simple construction of the lens and of the low price of Ferroxdure, the new electron lens is also cheaper than existing lenses for this purpose.